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INDIAN IGY PROGRAMME
—ACHIEVEMENTS

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CONTENTS

ERRATA

Page No.	Line	
3	13	delete 'a' and read as 'entirely wrong'
5	33-34	delete '(in Batavia, Capital of Dutch East Indies)'
6	6	Add bracket thus: '338 pp mv)'
11	Table 1 3rd Column	Read 'Mathur' for 'Mattur'
13	Figure 5	delete 'present' in caption
17	Line 13	delete 'during' and insert 'about'
19	Last para Line 8	Read 'cosmic' for 'comic'
22	Line 9	read 'of' for 'ot'
31	Line 26	read 'radio' for 'ratio'
44	Line 2	read 'for' for 'from'
50	Line 30	'read particle' for 'practicle'
58	Figure 37	Read 'Figure 17' for 'Figure 7'. Read 'Waltair for 'Wattair'
59	Figure 8	Read 'Figure 18' for Figure 8'
61	Figure 20	Add '(after Rastogi)' after caption
62	Figure 21	Figure got inverted
64	Line 3	read '$(n{\sim}3/4)$' for '$(n{\sim}\chi 3/4)$'
64	Line 30	Read '$(f \geqslant fH)$' for '$(f \geqslant fh)$'
68	Line 7	read '4.7×10^{-12} cms^3/s' for '4.7×10^{-2} cm^3/s'
69	Equation	Read '$q = \eta A\ (XY, \lambda)$' for $q = \eta A(XY_h, \lambda)$'
70	Equation in 'Region F'	Read '$O + h\nu \xrightarrow{\lambda\lambda 170\text{-}900} O^+ + e$'
72	Equation	Arrow should start after 'α_D'
79	Line 22	Read 'flares' for 'Flares'
80	Line 3	delete '(double star)'
84	Table 11	replace '$\leqslant 13$' with '$\geqslant 13$'
86	Last line	delete the last line of caption Add in caption 'Figure 29(a)'
89	Line 10	read 'L_α' for '$L\alpha$'
98	Line 32	Read 'Came' for 'Come'
113	Caption in Figure 48	delete 'source'
122	Line 26	Read 'Egedal (1947)' for 'Egedae (1947)'
130	Line 19	Add ';' after 'anthropogenic'

1. Introduction

The IGY started on July 1, 1957, and continuing in an extended capacity through IGC (International Geophysical Cooperation) till December 31, 1959, marked a watershed in Indian scientific efforts on the study of our planet and the sun. Coordinated national efforts under a framework of controlled intercomparison and specified conditions were, perhaps, introduced for the first time. There was also, for the first time, an organised entry of Indian science into international arena. Much of the coherence in the nationally coordinated programmes that has now become possible in aeronomy and planetary sciences—an outstanding example is currently operating Middle Atmospheric Programme—is a consequence, sometime direct, of this beginning of organised research in India.

Twelve distinct fields in which the IGY programme was divided had three major objectives as follows:

(1) The *interior and surface of the earth* involving fields of Geomagnetism, Latitudes and Longitudes, Glaciology, Oceanography, Seismology and Gravimetry.

(2) The *atmosphere of the earth* from the surface to the exosphere, involving fields such as Meteorology, Aurora and Airglow and Ionosophere.

(3) The *radiations*, electromagnetic and particles, coming from the sun and from outside the solar sytem and their interactions with the terrestrial environment.

2. International Programme Before IGY And Indian Situation

2.1 The First Polar Year

The story of IGY, however, began almost 100 years ago when the First International Polar Year enterprise (IPYI) was undertaken. It all began with the difficulties experienced and the ideas expressed by an Austrian Naval Officer, Karl Weyprecht, who had commanded the Austro-Hungarian Polar expedition of 1872-74. He felt that it was time to carry out scientific observations in polar regions on the physical conditions of the earth and the air in addition to mere geographical ventures. Weyprecht first presented his views at a meeting of the Academy of Sciences in Vienna in January 1875 and in 1877 a detailed scientific programme was presented

to the International Meteorological Conference in Rome. However, the war in South Eastern Europe intervened. The Congress finally met in Rome in the spring of 1879. It endorsed the programme and appointed an International Meteorological Commission and the first International Polar Conference was organised at Hamburg in October 1879. It was attended by nine delegates representing Austria, Hungary, Denmark, France, Germany, Netherlands, Norway, Russia and Sweden. The Conferance decided that *eight stations* suitably distributed in the Arctic region was the *minimum number* necessary for an useful programme, named these stations, and specified the duration of the programme from the autumn of 1881 to the next autumn. A permanent International Polar Commission was formed with Dr. G. Neumayer of Hamburg as its first President.

At the second International Polar Conference (convened in Berne in August 1880 to coincide with the meeting of International Meteorological Commission), definite promises of participation were reported from four countries—Austria, Denmark, Norway and Russia. Since eight Stations laid down as the minimum essential network were not available, it was decided to postpone the beginning of the operation to the autumn of 1882.

It was tragic that Weyprecht did not live to see the beginning of the programme that he initiated. He died on 29 March, 1881. However, the scientific programme and its objectives that finally emerged were based on his ideas and his rich experience in the polar phenomena.

There were several limitations of the programme. Firstly, it covered only a limited region—the Arctic. Secondly, even for the Arctic the scientific activities were intended to cover only auroras, geomagnetism and meteorology. The Ionosphere had not yet been discovered. Thirdly, there was not much organised international scientific activity at that time. The participating countries had experience of polar expeditions but little experience on technical observations, and the instrumentations were primitive. Amongst the expeditions that were mounted, the French expedition to Cape Horn was the only one to make extensive use of self-registering instruments for meteorological and magnetic parameters. The concept of choosing special days for intensive observations (later to become an important element during the IGY) was, however, introduced. The "Term Days" for the magnetic observations were 1st and 15th of each month (excepting for January when it was 2nd instead of 1st) and were made strictly according to Göttingen time at the exact hour and at 5 minutes intervals from midnight to midnight—a reminder to the influence of Gauss.

The main thrust of the programme was observations of the aurora and their relationship with magnetic variations. The magnetic observations

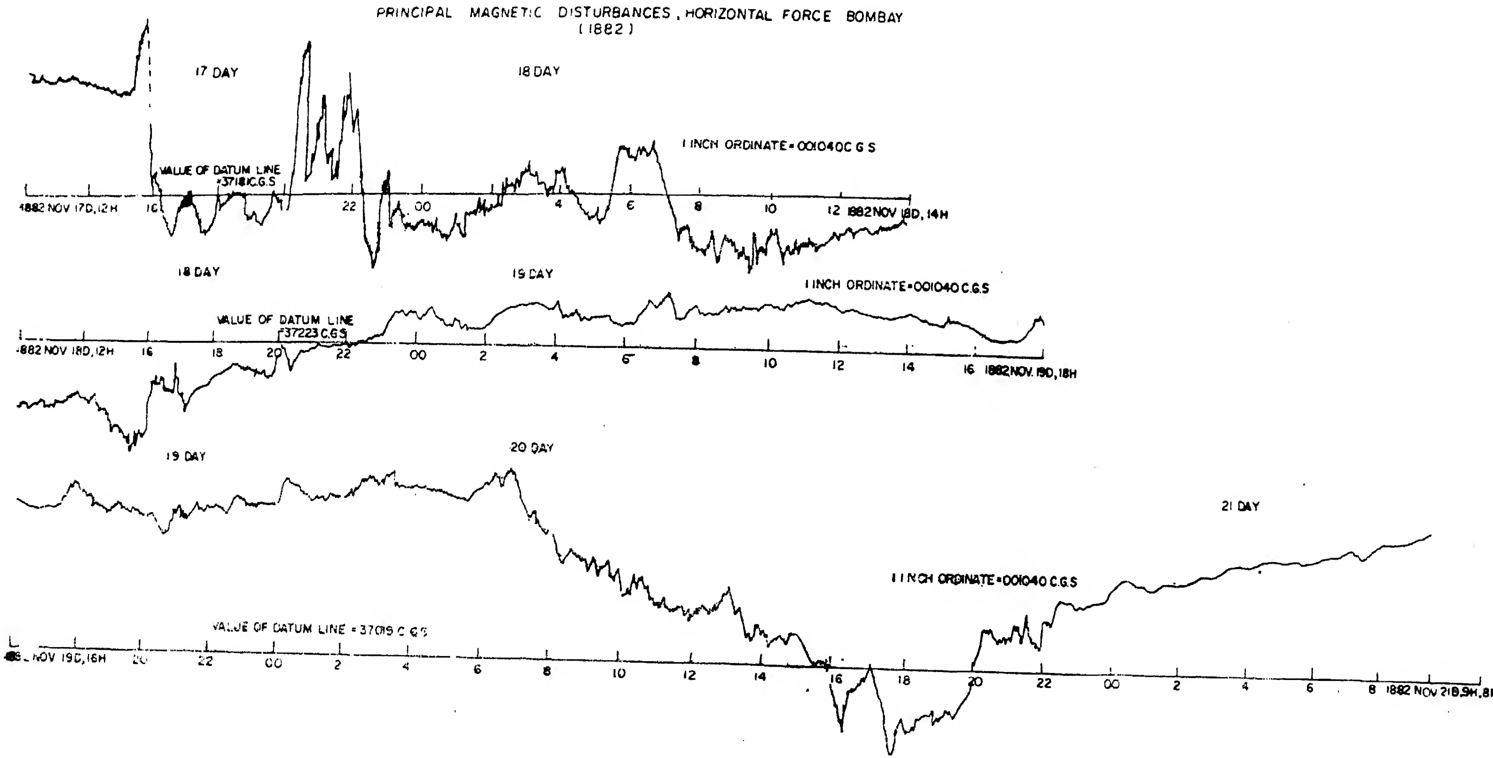


Figure 1. Magnetic storms recorded at Colaba Observatory on 17th, 18th and 20th November, 1882 (Courtesy: Director, Indian Institute of Geomagnetism, Bombay).

themselves were discontinuous and not entirely reliable, but provided the basic foundation for synoptic observations for the later years. It was also fortunate that IPY-1 was a year of considerable sun spot activity (the annual mean for 1882 was fairly high, about 62, though considerably less, as we will see, than that during the IGY). Of the 12 magnetic storms classified at the Greenwich as the greatest during the 80-year period 1874-1954, 2 occured within period of 3 days on 17 November and 20 November 1882. The Colaba observatory, which was by then operational (but did not participate in IPY 1), recorded some of these storms, an example of which is shown in Figure 1.

At that time the information on the height of the aurora was uncertain. To improve this information, observations were taken from stations 5 km apart. This, we now know, was an entirely a wrong choice of distance for the auroras are located at heights around 100 km. There was also the problem of communication between the stations.

This was a period of relatively high solar activity. It was also the year of the great volcanic eruption of Krakatoa; the eruption (occuring in August 1883) sent atmospheric waves twice around the earth and set up tidal waves that were recorded far across the Indian and South Atlantic Oceans.

A number of expeditions to the polar regions were organised. Details of several of these expeditions have been published (Annals of IGY, Vol. I). These include the Austrian Expedition to Jan Mayen, British-Canadian Expedition to Fort Rae (Great Slave Lake), the Danish Expedition to Godthaab (West Coast of Greenland), Dutch Expedition to Port Dickson, the Finnish Expedition to Sodankylä (North Finland), the French Expedition to Cape Horn (Tierra Del Fuego), the German Expedition to Kingua Fiord (Cumberland Sound) and South Georgia Island (South Atlantic Ocean), the Norwegian Expedition to Bossekop (North Coast of Norway), the Russian Expedition to Ssagastyr (Mouth of River Lena, Siberia) and Karmakule (Moller Bay, Novaya Zemlya), the Swedish Expedition to Cape Thordsen (Spitsbergen), the U.S. Expedition to Lady Franklin Bay (Grinnell Land and Point Barrow (North Coast of Alaska). Map of the distribution of stations in the Arctic during IPY-I is shown in Figure 2.

Much of the care and precaution that were taken during the IGY to ensure intercomparison of data collected from different institutions from diferent places with different instruments were also evident at that time. Measurements were taken to standardise instruments used for meteorology and geomagnetism. Corrections to be applied to meteorological instruments were determined beforehand at the Central Observatories and most cases were re-evaluated at the end of the expeditions. The instrumental constants

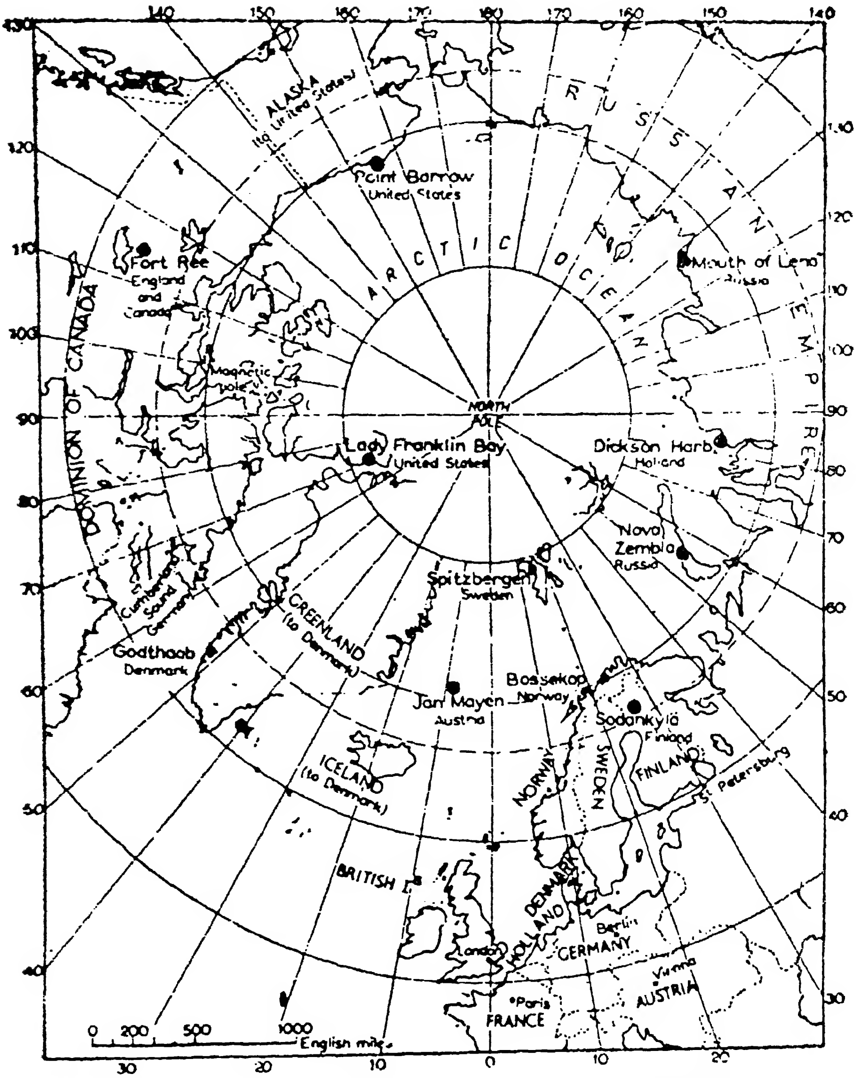


Figure 2. Map of the Arctic region showing the positions of the 1st International Polar Year Stations. (Source: *Annals of IGY*).

of the magnetometers, and temperature coefficients were also determined in advance.

India played no part during the 1st Polar Year nor did any of the other equatorial countries.

All the expeditions were not equally successful nor were they undertaken at the same time. Two American expeditions left before the Polar Year began: one under Lt. A.W. Greely in June 1881 to Lady Franklin Bay, the other under Lt. P.H. Ray in July to Point Barrow. The Russian Expedition to the Mouth of the Lena left St. Pebersburg in December 1881. The majority of the other expeditions departed in May, June and July of the same year. Most of the expeditions went smoothly with the exception of U.S. expedition to Lady Franklin Bay. Much of the results were eventually published although not in all cases immediately. Certain publications were obligatory. These were brought out in a series of official reports. Of the 9 volumes published, by far the most important were the six concerning the obligatory observations: botany, anthropology, geology and zoology. Results from the Netherlands expedition were not published till 1910. The most extensive were the results from the French expedition to Cape Horn.

Utilisation of these results was also uneven. Production of daily charts of the North Atlantic by the British Meteorological Office and the South Atlantic by the Deutsche Seewarte were quick. Auroral observations which formed an important part of this programme and were extensively carried out over the Arctic resulted in some excellent studies, but were nevertheless inadequately utilized. On the other hand, synoptic studies of magnetic disturbances and variations in magnetic fields formed the basis of later important studies on geomagnetism, magnetic storms and their relations with occurrences and intensities of auroras by Alfven, Birkeland and Chapman. Chapman later wrote: "the data from Polar Year 1 provided the main basis for such synoptic studies when, in 1926, I first realized the nature of the electric current system in the polar Ionosphere that generate the intense Arctic and Antarctic magnetic disturbances and these still remain true upto 1935 when my first qualitative sketch of the current system made roughly quantitatively".

Some of the results were unexpected. The effects of the Krakatoa volcanic eruption largest eruption during the last 100 years (in Batavia, capital of the Dutch East Indies) in 1883 could be monitored extensively, globally and as a function of time for the first time, although the 1815 eruption of Tambora was much larger. The telegraph had been invented; within hours news of the eruption was telegraphed round the world. Every barograph in the world recorded the pressure oscillations over a period of 5 days; tidal gauges recorded sea waves thousands of kilometers away. Volcanic dust shielded out solar radition lowering global temperature by as much as 5°K. A centennial perspective of this explosion has been given by Simkin and Fiske (1983).

Another important result was that obtained by the French expedition.

During this expedition, concentration of CO_2 was measured both in the Northern and Southern hemispheres. Even at that time there was realisation in scientific circles about the increasing production of CO_2 from industrial effects. The French observations gave the following results: 284 ppmv for the Northern hemisphere and 256 in the southern hemisphere (as against present value of 338 ppmv thus indicating the effect of industrial activities in atmospheric pollution.

2.2 The Second Polar Year (IPY 2)

The central Figure for the First Polar Year was Col. Weyprecht. The central figure for Second Polar Year was La Cour (who developed the quick-run magnetograph that was to be one of the most important equipments for the Second Polar Year). The idea of IPY 2 was first proposed in 1927 in Hamburg by Georgi at a meeting of Deutsche Seewarte.

There ware several reasons for this suggestion. One was the availability of some new instruments and the other was the discovery in the intervening period of several new phenomena. One such phenomenon was the discovery by Georgi of the presence of very strong winds at heights between 10 to 15 km, essentially independent of the surface pressure fields, now known as "jet streams", first observed over Northern Iceland in 1926-27 with pilot balloon ascents and soon over Greenland Sea. Secondly the synoptic study of magnetic disturbances initiated during IPY1 had been pursued vigorously by Birkeland by organising a new Arctic expeditions of his own between 1899-1903 and it was clear that the study of magnetic disturbances had promise. Thirdly, the First Polar Year was organised during a period of relatively high solar activity although, as we will see later, not as high as the IGY. It was felt that observations should now be taken for a quiet sun, since it was clear that occurrence and details of magnetic disturbances and auroral phenomena are related to the activity of the sun. Fourthly, it began to be realised that difficulties in understanding what happens at one particular place are often due to the vast scale of the various phenomena acting on one another and consequently the limited nature of the network during IPY 1 (the stations were primarily limited to the Arctic region) was not sufficient. It was necessary to extend such measurements to all possible latitudes. Fifthly, the Ionosphere had meanwhile been discovered. In 1925 Appleton and Barnett had discovered the existence of ionised layers in the upper atmosphere. This had been followed in 1926 by direction finding measurements of Simth Rose and Barfield and by the pulse experiments of Breit and Tuve in the USA. This discovery of ionised layers in the upper atmosphere that allow radio waves to travel around the curved surface of the earth over long distances excited Indian scientists also and in 1930 Professor S.K. Mitra and his students in Calcutta

using the Calcutta Station of the Indian State Broadcasting Service and a simple receiving equipment at a distance of 70 miles from Calcutta were able to obtain the first definite experimental evidence of the existence of an ionised layer over India in 1930.

La Cour has given an excellent account on the important changes in theoretical concepts between the 1st and the 2nd Polar Year. We quote : "*At the time of the First Polar Year the atmosphere was considered to be an insulating material-at least when rain was not falling. We now know that a lively and varied electrical manifestation is occurring everywhere in the atmosphere. We have become acquainted with ions; we know that milliards and milliards of these minor bodies of various types are swarming in the atmosphere, providing centres of condensation for precipitation and forming the conducting layers that make wireless telegraphy and broadcasting possible over long distances. We know that these corpusculars flow in great currents through the pure transparent air at great heights above our heads, these currents sometimes amounting to tens of thousands of amperes. We know that corpuscles arriving from interstellar space and entering the atmosphere with enormous velocities are incessantly bombarding our globe and disrupting atoms that had previously been considered unbreakable; we know that the corpuscles light up the magnificient draperies of the polar aurorae, hanging some hundred of kilometers above the snowy stretches of the northern and southern polar regions and that they block the path of wireless communication. Moreover we know that the rain as also the dust damps the free play of these small ions and increases not diminishes the insulating properties of the air.*" A remarkably clear exposition of the state of knowledge that we find difficult to improve upon even at this stage.

The economic depression in the thirties threatened to curtail and even cancel the programme. However, persistence of La Cour prevailed; 44 nations responded to his invitation resulting in establishment of almost 100 stations in the polar and sub-polar regions. The original plan, however, suffered to some extent. No stations were established on the Antarctic or in the region south of 60°S and only four carried out observations on the sub-Antarctic Islands. The number of magnetic stations in the American Arctic, European Arctic and in Africa increased respectively from 3,5 and 1 to 11, 15 and 16 with automatic instruments.

Another aspect was the introduction of important developments and techniques. The meteorological and magnetic recording instruments were by now greatly improved. The radiosonde was still in its infancy but the preparation for the manufacture of some 100 instruments speeded up this development very considerably. A considerable number of instruments became available within a few months of the beginning of the programme.

For geomagnetism a major advancement was the development of a special quick-run magnetograph designed by La Cour himself. These magnetographs became so useful for the detailed studies of rapid magnetic variations that they have been used ever since. The increased speed allowed reliable estimation of the exact moment of occurrence of certain phenomena such as the sudden commencement known to occur practically simultaneously over the globe and encouraged study concerning propagation of magnetic disturbances over the earth. Some 40 stations distributed over the globe were equipped with quick-run recorders; the time of occurrence of a magnetic disturbance could be determined with an accuracy of about 2 s. There were other important instruments: a small magnetograph that the Belgian scientists launched in large number to great heights in the stratosphere; instruments for the absorption of cosmic rays capable of affecting the very delicate measurements that reveal the presence of this radiation; and the introduction of radio techniques for ionospheric measurements.

India participated for the first time in the second Polar Year. This participation came mainly from the group of S.K. Mitra in Calcutta. The group, as mentioned earlier, had already built up experimental techniques including pulse techniques for radio reflection from the ionospheric layers. For the IPY Mitra's measurements were primarily concerned with the determination of the equivalent heights of reflection (in the E region) of radio waves of 75 meter wavelength at normal incidence. He obtained an average height of 75-80 km for the E-region, somewhat lower than that measured at high latitude stations. He also measured equivalent height of the F2 region on a number of frequencies and showed seasonal and diurnal variations about a mean value of 250 km. In those early years, ionospheric scientists were concerned with : (a) whether the ionisation is caused by solar electromagnetic radiation or by corpuscles and (b) the nature, composition and variability of ionisation. An interesting observation from the calcutta group that intrigued many scientists of that time was the detection of echoes from very low altitudes around 55 km which S.K. Mitra referred to as the C-layer.

An important contribution was his ionospheric observations at Calcutta during the annular solar eclipse of August 21, 1933, to judge the relative roles of UV radiation and corpuscles in the formation of the E and F regions. With transmitting and receiving stations 7 km apart and using different wavelengths, critical frequencies (and hence electron densities) were measured for both E and F layers for the eclipse (August 21) and control days (August 20 and 22, 1933). The results obtained by him are shown in Fig. 3. The decrease in ionization in the E region on the eclipse day from 8 AM reaching a well-definied minimum 20 minutes after the

optical maximum made him to conclude that untraviolet radiation must be the principal ionizing source for the E-layer.

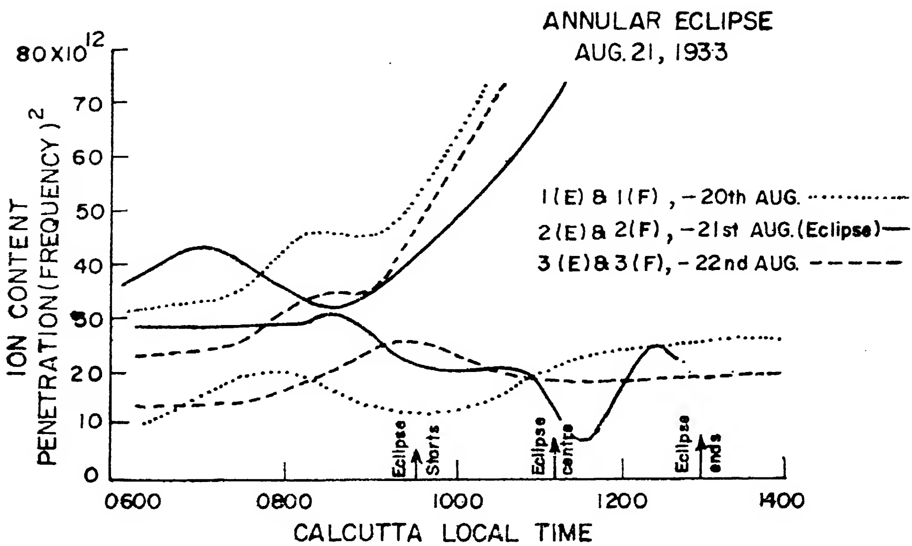


Figure 3. Results of Ionospheric observations during the Annular Solar Eclipse of August 21, 1933 obtained by S.K. Mitra.

There was participation from India in the area of meteorology also. Reports on Indian observations were prepared by S. Basu, Ram Sahai and K.G. Kabraji and also by N.K. Sur and K.P. Ramakrishnan. The Colaba observatory had already started operating (1846) but there was apparently no appreciable involvement of this observatory in the Polar Year Programme.

2.3 Period between IPY-2 and the IGY

Between 1933 and the beginning of the IGY, many remarkable advances were made in geophysical sciences and new techniques were introduced. The most spectacular of these was the use of rockets, begun shortly after World War II in the USA and later in the USSR.

The Indian scientific scene was also fast changing, and there were significant new developments in India in ionospheric physics, in solar physics, in geomagnetism, in cosmic rays and several areas of solid earth geophysics.

In ionospheric physics a major event was the preparation of a document by S.K. Mitra in 1935 entitled "Report on the present State of our

Knowledge of the Ionosphere" which he presented in a meeting of the National Institute of Sciences of India (the name under which the Indian National Science Academy was known at that time) in August 1935. This was very well received. This prompted S. K. Mitra to think of writing a book on a larger area—the Upper Atmosphere—of which the ionosphere is only a part. In the preparation of this volume he took 10 years and had the assistance of large number of students. The book was eventually published by the Asiatic Society of Bengal in 1947 (the Western press to which he had approached initially did not agree to the publication feeling that it has limited sale value). The 2000 copies that were printed were exhausted very rapidly and in 1950 he was asked by the Asiatic Society to publish a revised second edition. The second edition was published in 1952.

The publication of the book "The Upper Atmosphere" can be regarded now as one of the major events in the progress of atmospheric sciences in India. The discovery of the ionised region and its great potential in the area of radio communication had blinded people to lose sight of the fact that this ionised region *is a product and a part of the neutral atmosphere* consisting of a wide variety of species, some of which are present in excited states, some present in very minute quantities as trace gases and that interaction of this neutral atmosphere with the ionisation and the interaction of the different species of the atmosphere must give rise to a variety of phenomena that require study. This concept of a wider perspective of the ionosphere as a part of the upper atmosphere, later to be reintroduced as 'Aeronomy', was a major contribution of Indian science. Even at that time he had an entire chapter on the earth's thermal structure and developed model profiles of atmospheric temperature and density (Table 1 & Fig. 4) that happened to be one of the few that Soviet scientists could use to calculate lifetime of the first satellites launched. S. K. Mitra was also one of the scientists that pioneered the chemistry of excited species and the mechanisms of origin of different kinds of emission in the upper atmosphere, now called the airglow.

The next major event for the Indian science in this area was the establishment of a laboratory in Ahmedabad by Vikram Sarabhai with K. R. Ramanathan (who had just retired from the India Meteorological Department) as its first Director. The combination of Sarabhai and Ramanathan was remarkable, Ramanathan bringing in the meteorologist's view of the role of dynamics in the broader areas of upper atmosphere and Sarabhai with his deep interest in Cosmic rays and Astronomy.

The Radio Propagation Unit was formed at the NPL in 1954. Predictions of the ionospheric regions needed for the medium and high frequency broadcasting at that time were obtained either from England or from

Table 1 *Model of upper atmosphere (a) an older model given by S. K. Mirra (1952) and (b) Mitra and Mathur (1960) based on Rocket and Satelite data*

	Density (gm/cm^3)		Temparature (°K)	
Height (km)	S.K. Mitra's model (1952) (a)	Mitra and Mattur Model (1959) (b)	S.K. Mitra model (1952) (a)	Mitra and Mathur model (1960) (b)
800	3.67×10^{-17}	6.00×10^{-17}	3040	2068
500	7.00×10^{-16}	1.54×10^{-15}	1840	1591
300	2.11×10^{-14}	4.97×10^{-14}	1040	1023
130	—	2.74×10^{-11}	—	462
110	4.98×10^{-19}	—	270	—
100	1.74×10^{-9}	—	240	—

Australia and it was felt that a local system would be of advantage. The RPU started the job of coordinating ionospheric data in India—by this time several ionosondes were in operation: in Calcutta, in Ahmedabad, in Delhi. A new ionosonde (C4) was set up at the NPL and as a prelude to the longterm prediction work this unit also undertook the prediction of the solar activity. This has continued now for some 30 years and has proved remarkably good (see for example, Figure 5). Recognising that use of radio frequencies must in future extend beyond the limited range of 500 KHz-20 MHz, observations were initiated using natural emissions both above 20 MHz, and below 500 KHz. In the first case A. P. Mitra introduced a technique which had been developed a few years earlier by him and Shain (1951) in Australia for the reception of cosmic radio noise; this was later to be extensively used during the IGY. For measurements below 500 KHz, monitoring of atmospherics were initiated at a number of forquencies (27 KHz and 100 KHz) and radio transmission from Tashkant at 164 KHz. Both the riometer and the atmospherics were commissioned for the detection of solar flares, and formed an important part of global IGY efforts.

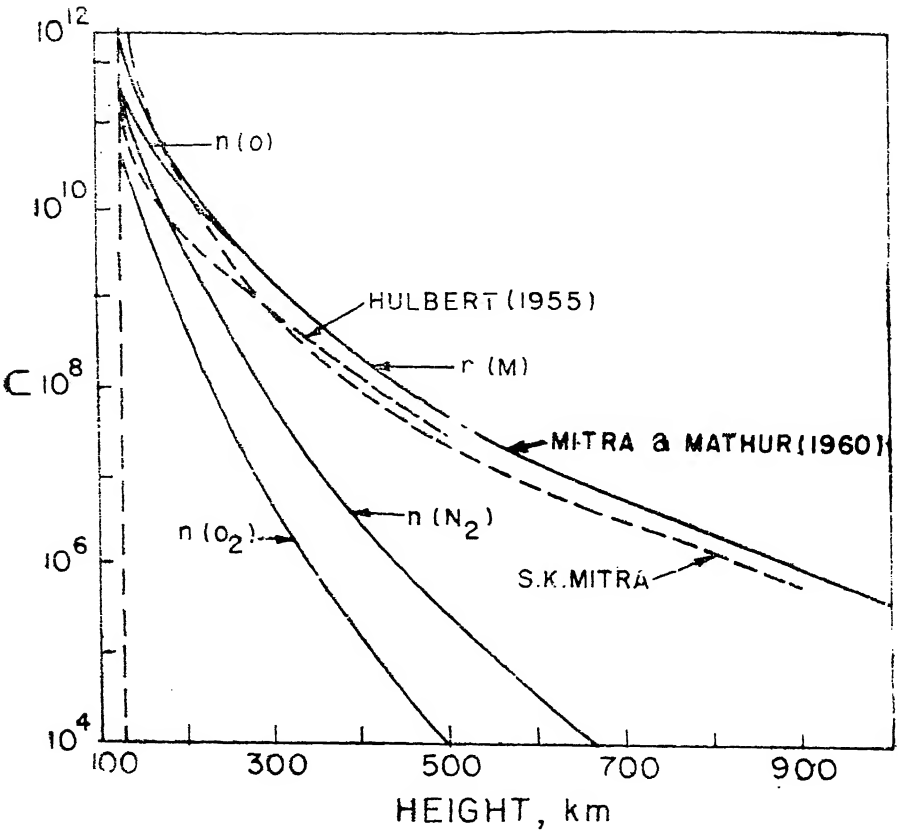


Figure 4. Distribution of n (O_2), n (O), n (N_2) and particle density for the IGY Mitra-Mathur model. S. K. Mitra's (1960) and Hulbert's (1960) models are given also in the figure for comparison. Source: Mitra S. K. (1960) and Mathur S.B. & Mitra A.P. (1964).

There was, therefore, a reasonably sound base of activities in upper atmosphere when the IGY came.

The tradition of solar and geomagnetic research in India was even older. In the second half of the nineteenth century, three total solar eclipses occurred in India: this prompted experiments on Indian soil, with some pioneering results. In 1868 eclipse first indication of an unknown element on the sun was observed from spectrographic observations by Janssen. Later during the total solar eclipse of 1871, Janssen discovered the Fraunhofer corona from the Nilgiri hills. During the eclipse of 1898, Evershed recorded the near UV spectra of solar corona from Ratnagiri. Kodaikanal observatory, which has produced most of solar work in the

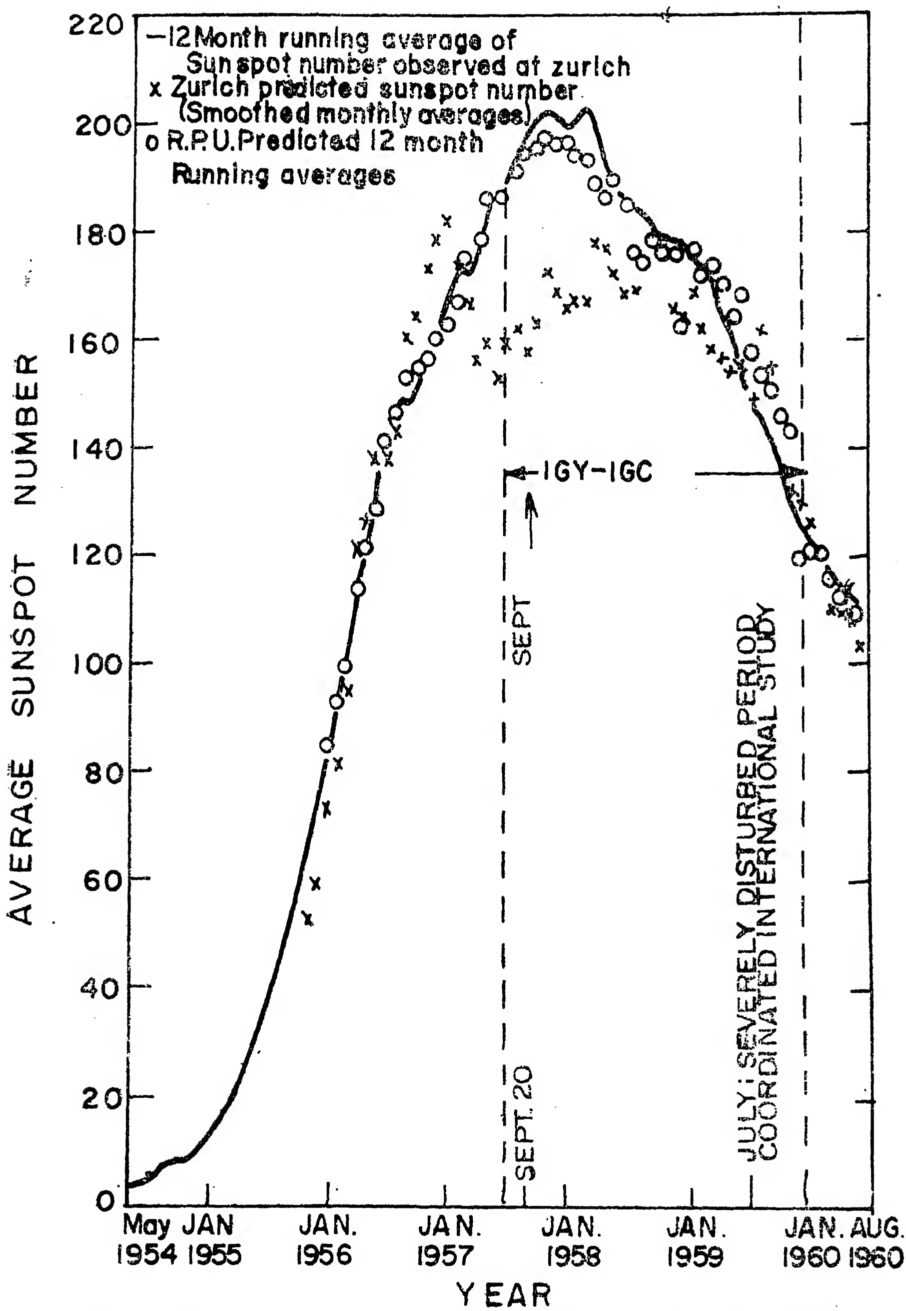


Figure 5. Details of present sunspot cycle and predictions for Zurich and NPL, Delhi.

country, started regular observations in 1901. Evershed effect (radial motion of gases around sunspot groups) was discovered in 1909. The Nizamiya Observatory was also established during this time. Saha's ionization theory, a landmark in solar physics, came in 1921. The UP State Observatory at Nainital as well as the Nizamiya observatory in Hyderabad came much later, but were operating observatories at the time of the IGY with strong solar monitoring programmes. Radio observations on the sun were just beginning : directly by observations of radio emission from the sun at 100 MHz in Kodaikanal (as early as 1952) and later in cm wavelengths at Delhi (NPL) and Ahmedabad (PRL) and also indirectly through ionospheric signatures of the increased XUV radiation (Sudden Ionospheric Disturbances). The NPL had already organised a powerful system of ionospheric flare patrol by using atmospherics, reception from Tashkant at 164 KHz, essentially continuous sweeping of the ionosonde and the use of cosmic radio noise emissions.

Similarly in geomagnetism a rich and long tradition existed. At the time of the IGY there were nearly hundred years of observations in Colaba and Alibag observatories. At Colaba magnetic observations were started in 1846; the observatory was shifted to Alibag in 1905. Subsequently geomagnetic observations were started at the Astrophysical observatory at Kodaikanal. The concept of electrojet currents came from the data collected at Alibag, Kodaikanal and Madras.

A powerful cosmic ray programme was also in progress in India, primarily in TIFR in Bombay and in the recently established Physical Research Laboratory in Ahmedabad (under Sarabhai). Sarabhai had already established a network of stations in the equatorial region with geiger counter telescopes of limited solid angle to elucidate some of the meteorological and extra-terrestrial causes of the daily variation of meson intensity. The network was as follows:

Ahmedabad	23.5°N, 72.5°E, 50 m
Kodaikanal	10.2°N, 77.5°E, 2340 m
Trivandrum	8.5°N, 77.0°E, sealevel.

In TIFR the emphasis was on the capability of making high altitude balloon ascents to carry cosmic ray instruments to high altitudes to sample the radiations before they get modified. During 1945-1955, in the early years, clusters of rubber balloons were used ; later large constant volume polyethylene balloons.

3. The International Geophysical Year—Genesis and Background

3.1 Genesis

The idea of holding another International programme 25 years later (instead of 50 years) was brought up in an informal gathering by Dr. Lloyd Berkner at the home of Prof. J.A. Van Allen (whose name was subsequently associated with the discovery of radiation belt trapped in the earth's magnetic field) on 5th April, 1950. He felt that in view of the rapid advancements since 1933 in geophysics and in various techniques specially those relating to ionosphere, a further operation was necessary. Furthermore, during the year 1957-58, solar activity would be close to its maximum whereas in IPY-2 it was near its minimum. The proposal was endorsed by those present (Van Allen, Chapman, Joyce, Singer and Vestine) and was formally brought to the Mixed Commission of the Ionosphere in 1950. The Commission endorsed the programme and its resolution that the third International Polar Year be held in 1957-58 was transmitted to the three Unions sponsoring the Commission (URSI, IAU and IUGG) and the Bureau of ICSU. The ICSU set up a Special Committee of its Council and appointed on 16th May 1952 at a meeting of the Bureau, Col. Herbays as the Convener of the Special Committee. In parallel with this action letters were sent to the adhering organisations of the ICSU with a request that special National Committees be formed in each country.

In the formulation of the international programme of the IGY, the contribution of K.S. Krishnan, as Vice President, ICSU, was substantial. In the words of Sydney Chapman, President, CSAGI:

> "I would specially write of his association with that remarkable world-wide scientific enterprise—the International Geophysical Year (IGY) 1957-58. Only his colleagues on the National IGY Committee for India can fully know the leadership and the support he has given, as President of that Committee, in developing India's IGY participation and programme. But the scope and excellence of that programme redounds to his credit..........Sir K. S. Krishnan has not only led and supported the plans for India's share in the IGY, he has also given it valuable support on the international level, in his capacity as Vice-President of the International Council of Scientific Unions (ICSU) for the past six years. This eminent position has given him a voice in the formation and progress of the Special Committee for the International Geophysical Year (CSAGI)—Comite Special de l'Annee Geophysique Internationale—over which I have had the honour to preside".

Meanwhile the Executive Committee on the WMO had pointed out that it would be better to change the name to "*International Geophysical Year*" so as to stress the need to extend synoptic observations of geophysical phenomena over the whole surface of the earth, a need that was also recognised by the International Meteorological Association and by the International Association of Terrestrial Magnetism and Electricity. At the ICSU Assembly in Amsterdam in October 1952, the change of name of the enterprise to the International Geophysical Year (IGY) was agreed and National Organising Committees adhering to ICSU were approached for their programmes. In March 1953, the Bureau of ICSU enlarged its special Committee to include representatives of IAU, URSI, and IUGG, representatives of WMO and ICSU and this enlarged Special Committee held its first meeting in Brussels from 30th June-3rd July, 1953.

It was decided that the programme would commence on 00 hours UT on 1st July, 1957 and continue for 18 months terminating at 24 hours UT on 31st December 1958. A 10-day test interval commencing at 00 hour UT on 20 June 1957 preceding the beginning of the IGY was also adopted. During the second Polar Years, studies of the ionosphere were added to the First Polar Years programme on meteorology, aurora and geomagnetism. During the IGY some more areas were included. One concerned the observation of the sun. Because so many geophysical phenomena related to phenomena occuring on the sun arrangements were made for it to be kept under observation as continuously as possible at the various solar observatories of the world.

For this the observatories at Kodaikanal and at Nainital were to play very important roles. Two unusual programmes concerned (a) Antarctic and (b) the intention to launch satellites during the IGY.

In the second Polar Year although the Antarctica was one of the targets, no measurements could be made because of curtailment of the programme. It was already clear that the Antarctica, one of the earth's continents, represents a major landmass with an area of about 1.60×10^7 sq. km. and that its unique position and its physical characteristics make it a region of unparalleled interest in the fields of geophysics and geography. In geophysics, Antarctica had several significant unexplored aspects: the influence of the huge ice mass on global weather and on atmospheric and oceanographic dynamics; the nature and extent of the Aurora Australis; the physical characteristics of the Antarctic ionosphere during prolonged night conditions. At the time of the second meeting of the Special Committee in Rome in 1954, 21 stations had already been planned or were already in operation for geophysical research in the Antarctica.

One of the most spectacular events was the launching of satellites. At the meeting on 11 September 1956 of the Special Committee in Barcelona, Academician I. P. Bardin of the USSR formally announced the intention of USSR to launch instrumented satellites during the IGY. These satellites were to be used for measurement of atmospheric pressure and temperature as well as of cosmic rays, micrometeorites, geomagnetic fields and solar radiation. The satellite programme was introduced during the IGY at somewhat late stage. A special Rocket and Satellite Conference was arranged to discuss the programme. Subsequently USA also announced its intention of launching satellites. Programmes of scientific experiments involving rockets were already in progress in a number of countries including the USA, USSR, U.K., Germany and France.

India showed interest during the IGY right from the beginning. Even as early as 1953, amongst the 12 observers from the 9 countries who participated in the meeting of the Special Committee of ICSU in Brussels and helped in planning the programme were T. V. Ramamurty of the NPL and V. A. Sarabhai of Ahmedabad. K. R. Ramanathan participated in some of the later meetings of the CSAGI and was largely responsible for the formulation of the plans for the IGY and the IGC. The Indian National Committee was formed in 1955 with K. S. Krishnan as Chairman and A. P. Mitra as Secretary. A programme of Indian activities was drawn long before the beginning of IGY.

3.2 Global Perspective and India's Special Position

The IGY was a remarkable event. It brought in a revolution in Indian science in several areas—in ionosphere, in cosmic rays, in geomagnetism, in solar physics, in meteorology and in several areas of earth sciences. A total of 64 countries eventually joined in the programme involving 2461 stations and the labours of many thousand scientists and technicians.

The special role played by the region near the geomagnetic equator was already known such as the presence and the complex nature of the electrojet straddling the geomagnetic equator and the curious phenomena of ionisation peaking not at geomagnetic equator but at dip values of about 30° away from it (the so-called Appleton Anomaly). Thus the regions around the geomagnetic equator had already assumed considerable importance in geophysical studies. In that context, India had a special significance (Fig. 6). Trivandrum was almost exactly on the magnetic equator, Kodaikanal on the fringe of the electrojet and Tiruchirapalli in the

middle of it. Further north Ahmedabad and Calcutta were nearly at the peak of the Appleton anomaly and they were (excepting Calcutta) all nearly around the same longitude: 75°E, an unusual advantage that was immediately recognized.

Furthermore, the IGY was also a poor man's programme. Irrespective of the scientific level of the country or of the institutions, there was scope for useful contribution from all. Some of the observations could be undertaken with relatively simple instruments, such as: the reception of signals from broadcast transmitters or atmospherics in the LF and VLF, experiments on atmospheric electricity, meteorological observations with groundbased sensors or with radiosondes that were being undertaken in any case as part of the country's weather service, photography of auroras with simple cameras on the ground, the simple telescopic arrangement introduced, after Sputnik I was launched, to obtain approximate positions of an orbiting satellite in the programme called "Moonwatch". It is interesting to note that although auroras are polar phenomena, these had sometimes been seen at low latitudes. These occur in years when the sun is specially active. India was specially approached by Sydney Chapman, President of the IGY Programme, who pointed out that such an aurora was observed over India on 4th Feb., 1872 over geomagnetic latitudes of 24°N to 10°N (Chapman, 1957). In accordance with Chapman's request a chain of 10 visual stations was organised in India by the India Meteorological Department. The watch was kept continuously during the periods of special intervals.

It was realised that a description of the earth and its atmosphere could only be achieved if the observation stations were carefully distributed. As in the first and second Polar years, special emphasis was laid on the Arctic. In addition, for the first time, a coordinated programme on the Antarctic was mounted. There were 302 stations in the Arctic and 66 stations in the Antarctic. Special meridians were selected along which station distribution was particularly numerous. These were the meridians of: (a) 70°-80° W from the North Pole to Canada along the eastern US Coast, the West Coast of Latin America to the South Pole, (b) 10°E (Scandinavia, the Middle Europe, Africa and part of the Atlantic Ocean) and (c) 140°E (through Alaska and Pacific Ocean).

The number of Indian stations participating in the various disciplines against the total number of stations all over the world are indicated in the Table 2. The total number of IGY world stations located in the Northern equatorial regions defined by $\phi < 20°$ where ϕ is the geomagnetic latitude, is also given for comparison. The Indian stations were mostly in this equatorial zone, but a few like Srinagar, Gulmarg, Amritsar, and Dehra-

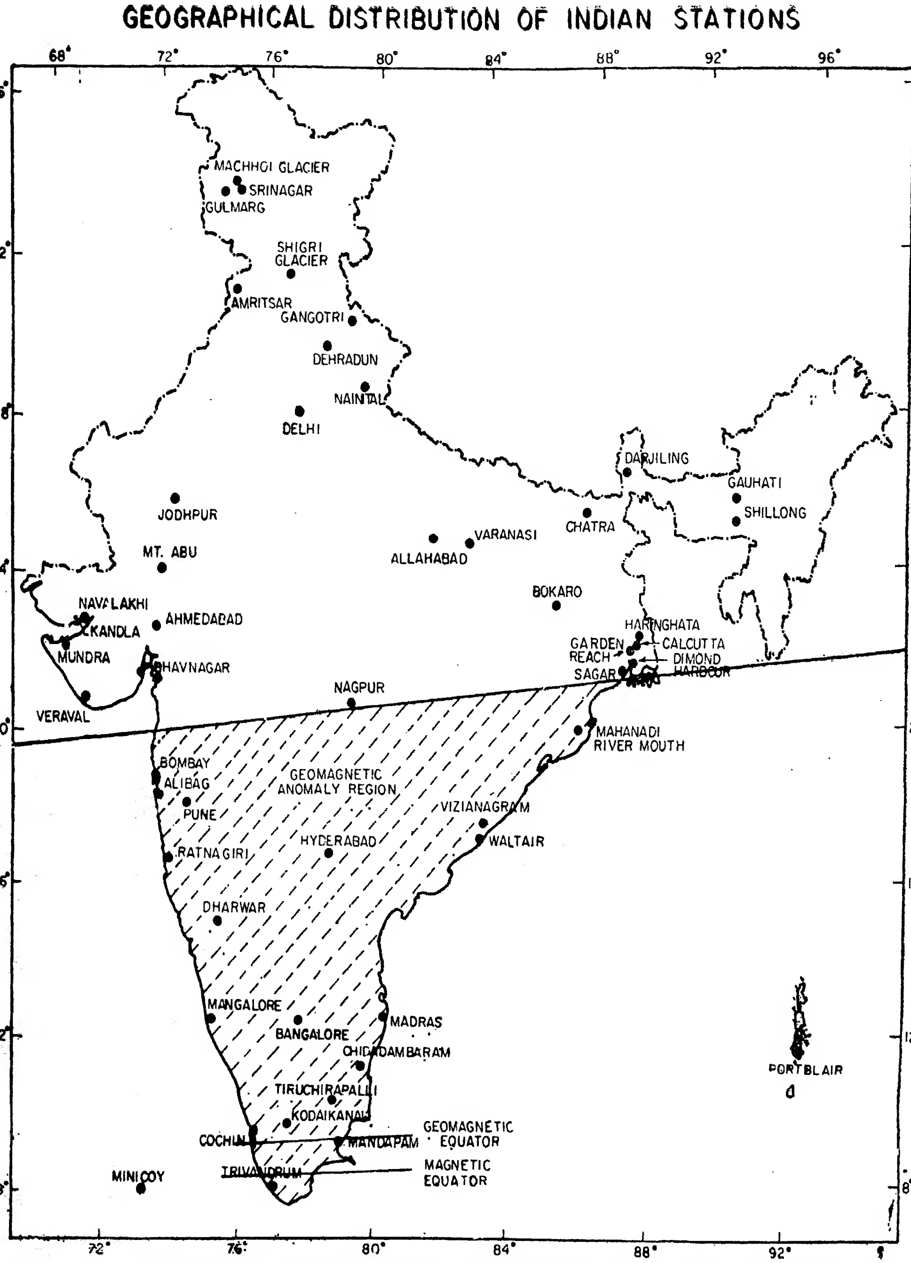


Figure 6. Geographical distribution of Indian Ionospheric stations (The shaded portion indicates the region of geomagnetic anomaly)

Table 2 *Station list—Global and Indian*

	Discipline	World Stations	Indian Stations	Northern Equatorial Stations
I.	World Days and Communication	69	1	10
II.	Meteorology	118	20	89
III.	Geomagnetism	223	6	18
IV.	Aurora and Airglow	81	5	4
V.	Ionosphere	284	11	33
VI.	Solar Activity	127	2	9
VII.	Cosmic Rays	128	5	8
VIII.	Longitudes & Latitudes	79	3	4
IX.	Glaciology	103	3	—
X.	Oceanography	301	23	50
XI.	Rockets and Satellites	76	1	5
XII.	Seismology	332	16	35
XIII.	Gravimetry	150	9	9
XIV.	Nuclear Radiation	400	6	30
	Total	3571	111	304

dun, and the Glaciers: Shigri, Gangotri and Mechhoi were located in the northern minauroral regions ($45° > \phi > 20°$)
In order to study the specially anomalous phenomena occuring in the equatorial region, a new ionospheric station was established at Trivandrum, slightly south of the geomagnetic equator (0.9°S) to act as a station doublet to Kodaikanal (0.6°N) in addition to other stations (Waltair, Madras, Tiruchirapally located within the anomaly zone, (Figure 6). Magnetic stations were established at Trivandrum and Annamalainagar (1.6°N), south and north of Kodaikanal, with Kodaikanal as the base station; and comic ray observations were made at Kodaikanal. A list of Indian stations participating in the IGY and the observational areas in each of these stations is given in Annexure 1.

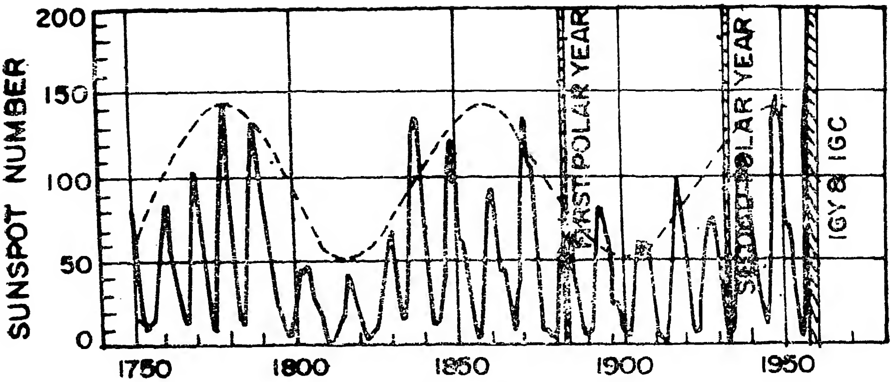


Figure 7. Sunspot activity since 1750.

3.3 Solar and Geomagnetic Conditions

One of the reasons for choosing 1957-58 for the IGY was to make observations during a period of high sunspot activity, since the previous Polar Years were held during relatively quiet periods. The choice was surprisingly good. The IGY coincided with the largest sunspot maximum in recorded history, the 12 month running average sunspot number exceeding a value of 200 at its peak. In Figure 7 the sunspot cycle during the IGY period is shown along with 19 previous sunspot cycles covering a period of over 200 years, and the periods for the IGY-IGC and the first two polar Years are indicated. The great difference in the sunspot activity between the IGY-IGC and the polar Years (62 and 8 respectively in IPY I and IPY 2) may be noted. Previous peaks of high solar activity were the years 1947/5 (150),

Table 3 *Occurrence of magnetic storms yearwise 1954-1960*

	1954	1955	1956	1957	1958	1959	1960	Total
Sunspot number	4	38	142	190	185	159	142	—
Storms with highest K_p of 7	2	2	9	12	12	7	9	53
Storms with highest K_p of 8	—	3	7	5	4	7	3	29
Storms with highest K_p of 9	—	—	1	6	3	2	2	14
All	2	5	17	23	19	16	14	96

1870. 6 (140), 1778.4 (150) but none comparable of that of the IGY. It will be noticed that during the entire period of 2½ years during the IGY and IGC unusually high solar activity was maintained. The 12 month running average sunspot number never went below 180 during this period and was around 200 for a substantial portion of the time. The monthly average sunspot number varied over the range 125-205. Predictions of the sunspot number made at Zurich and at the Radio Propagation Unit of New Delhi are also indicated in the figure 5.

As a result of the high solar activity, solar flares and magnetic storms occurred in great numbers during this period. Dodson and Hedeman (1960) reported that during the period July 1957 to December 1958, a total of 6762 flares were observed, of which 835 were of class 1^-,5389 of class 1, 497 of class 2 and 41 of class 3 and 3^+. Magnetic storms were also numerous, many of them severe. Kodaikanal reported 69 magnetic storms during the IGY-IGC of which 14 were classified as 'severe'. Five of these occurred in September 1957 and three in July 1959. *July 1959 in particular, was a period of great disturbance (severe magnetic storms in close succession) and a period of coordinated international study.* Bartels noted that of the 96 large storms (having highest K_p values of 7 and above) that occured during the seven years since the last quiet sun of 1954, 23 occurred in 1957 alone. Similarly, of the 14 storms having highest K_p values of 9 that occurred durring this period, 6 occurred in 1957 (Table 3).

3.4 Distribution and Preservation of IGY Data

3.4.1 Establishment of World Data Centres

An important arrangement was the establishment of a number of World Data Centres (WDC's) where observational data obtained during the IGY and IGC were collected, and made available to scientists all over the world. Several such Centres were established to insure against catastrophic destruction of a single centre and to meet the geographical convenience of, and provide easy communication for, workers in different parts of the world. For all disciplines there were three or more centres as follow:

Centre A : All disciplines USA

Centre B : All disciplines USSR

Centre C : These were different for different disciplines.

The data obtained in India during the IGY and IGC were despatched to these World Data Centres. Copies of such data were kept by the originating organisations, and for several disciplines, also by the Secretariat of the Indian National Committee for the IGY.

In India, coordinators were nominated for the various disciplines to facilitate despatch and ensure uniformity of data.

3.4.2 World Days, World Intervals and Alerts

During the IGY there were there classes of special days. On these days, special programmes were undertaken in the majority of the scientific disciplines included in the IGY programme. These three classes were:

(i) *Regular World Days* (*RWD*): These were three or four days each month, selected in advance. Two were consecutive days at the time of new moon. The others were times of unusual meteoric showers or near one of the lunar quarter phase. There were also adjacent days for control observations.

(ii) *World Meteorological Intervals* (*WMI*): These were a series of ten consecutive days in June, September, December and March. They coincided exactly with two 'Pentades' of the World Meteorological Organisation. The WMI always included an equinox or solstice. Special programme in meteorology were specified to be carried out during the WMI.

(iii) *Periods of Alerts and Special World Intervals* (*SWI*): These were designated on day-to-day basis by the IGY World Warning Agency, acting with the advice of forecasting centres throughout the world. "Alerts" warned observers that there was more than usual likelihood of the outbreak of magnetic, auroral and ionospheric disturbances as judged on the basis of observations on solar activity. During an alert, an SWI was declared on eight hours' notice by the IGY World Warning Agency. An SWI continued until terminated by the IGY World Warning Agency.

An elaborate arrangement was made to ensure rapid communication of Alerts throught the globe. For this purpose, the telecommunication system used depended heavily on the meteorological Data exchange systems and given in Figure 8 which also indicates India's location in the network. Alerts and SWIs issued by the IGY World Warning Agency were received at the IMD Sub-continental Meteorological Broadcast Centre at New Delhi, and rebroadcast according to the plan recommended by the WMO at 1900 UT and 1930 UT. The details of these rebroadcast are given below:

Call Sign : New Delhi-VVD 3.
Frequencies (KHz)-9930, 6978, 4060, 2505.

The message, supplemented by a brief summary of the solar and geomagnetic data of the Kodaikanal Observatory, was broadcast twice daily in plain language by All India Radio.

Simple Copy of Broadcast:

16.7.1957 11.15 PM AGI No. 46

Alert starts immediately at 1600 hrs GMT, 16th July, 1957.
Kodaikanal report on Solar Activity on 16th July, 1957.

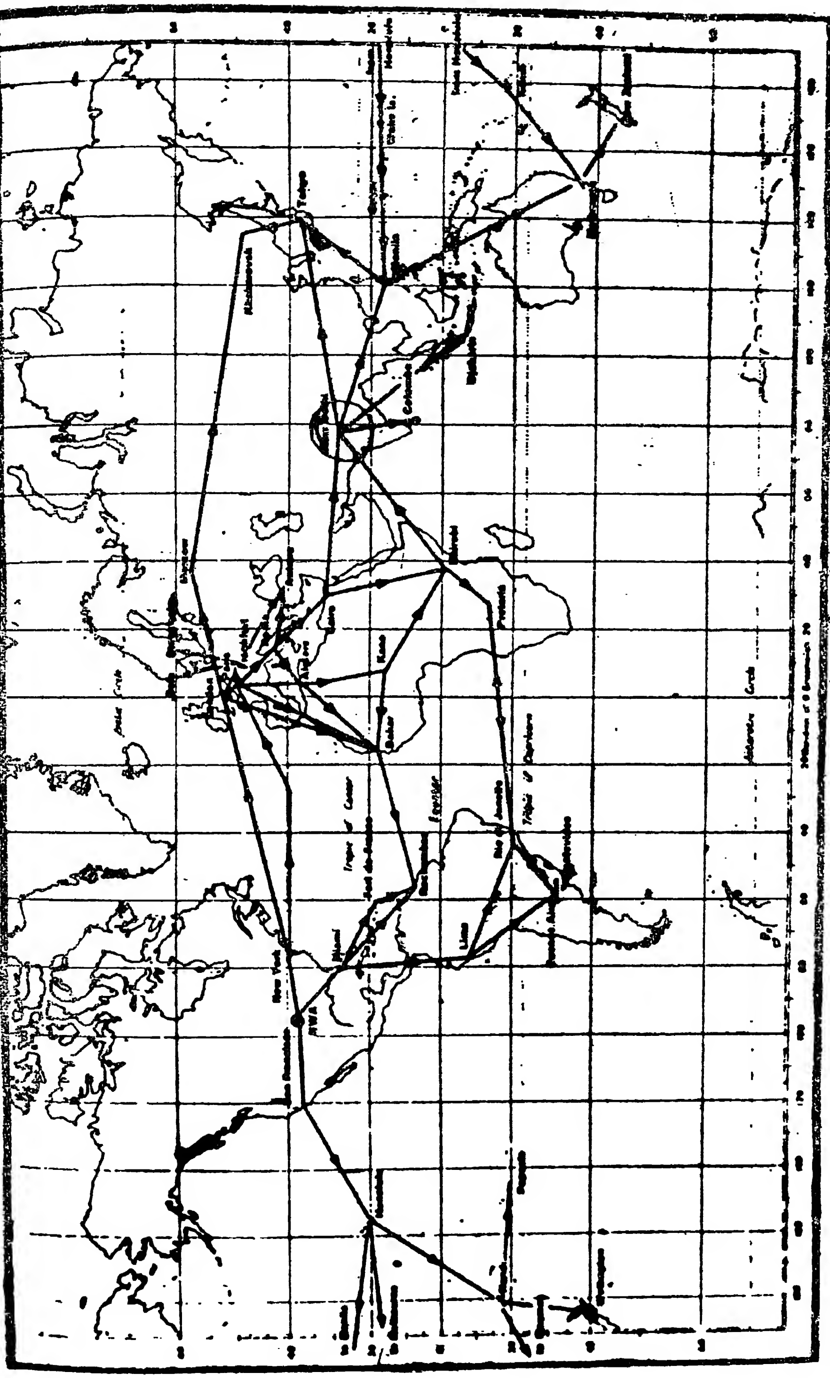


Figure 8. Map of the World showing the meteorological telecommunication channels for communication of SWI messages disseminated during IGY. (Source: *IGY Bulletin*).

Prominence activity strong. There were nine centres of activity on the disc. One on longitude 58°E and latitude 25°S showed fairly strong activity. Relative sunspot number 128. Magnetic activity for Monday almost calm throughout the day."

4. Indian Programme for the IGY

4.1 Meteorology

In meteorology the primary objective was the investigation of large-scale physical, dynamic and thermodynamic processes of the general circulation of the atmosphere and particularly of the following problems:

(a) Redistribution in the atmosphere on a planetary scale of momentum, absolute vorticity, entropy and all forms of energy.

(b) The large scale influence of friction and of surface topography on the balance of momentum, of energy and of absolute vorticity, and on the balance of the exchange of momentum and heat between the atmosphere on the one hand and the oceans and continents on the other;

(c) The pattern of the field of flow in low latitudes and the interactions between the circulation of the two hemispheres and between tropical and extra-tropical circulation;

(d) The horizontal and vertical distribution of ozone and water vapour (especially water vapour at high levels) and the distribution of precipitation (especially over the oceans) in relation to large scale weather situations:

During IPY-1 meteorology observations were made only at the surface; during IPY-2, at several heights as well as on the surface, by means of balloons carrying either balloonsondes, for which instrumental records could be subsequently recovered, or with radiosondes, which transmit information to the ground by radio. A major aim was to extend the exploration to much higher levels than before and over a much greater part of the globe than hitherto possible-especially in the tropics, where the troposphere was known to be at a much greater height (16-18 km) than at the poles (8 Km). At the standard meteorological stations distribution of air temperature upto a height of about 20 km was determined twice daily, and of wind velocities four times daily. On the Regular World Days observations were especially intensive and widespread, the temperature observations were made four times daily and up to a height of 30 km.

The Indian programme was contributed entirely by the India Meteorological Department. Upper air measurements were made through a

network of 13 radiosonde stations and 12 Rawin stations operating twice a day and recording temperature, pressure, humidity and wind in the upper atmosphere. Upper winds were also measured by 54 pilot balloon observatories spread over the country including the island stations at Port Blair and Minicoy.

Voluntary observing fleet from the merchant ships of Indian registration recorded observations out in the sea. Additional information in respect of weather was obtained from storm detection radars at Delhi, Calcutta (where the long range medium power radar Dacca 41 was replaced by a high power Japanese storm detection radar), Bombay, Nagpur and Poona.

Equipments for direction finding of thunderstorms by recording radionoise produced by lighting discharges in the VLF (27 KHz) were installed at New Delhi and Santiniketan. Preliminary fixes of thunderstorm positions were obtained.

To study the heat balance of the atmosphere and energy exchange between the sun, the earth and the atmosphere, the IMD established 4 radiation measuring stations at Delhi, Calcutta, Poona and Madras.

Even in this early stage a very strong ozone activity was in progress in India. The ozone programme envisaged operation of 4 stations: Srinagar, Mt. Abu, Delhi and Kodaikanal (the first two operated by PRL, Ahmedabad; the last two by IMD). Subsequently, two additional stations were established at Banaras and Kharagpur.

Continuous records of the electric potential gradient at the surface were taken at four stations: Poona, Bombay, New Delhi and Calcutta.

4.2 Geomagnetism

In Geomagnetism, three main problems of fundamental importance were emphasised :

(1) Study of the morphology of *magnetic disturbances* (*storms, bays or pulsations*) as a function of time and since these were known to be associated with overhead electric current systems, to be able to draw them from a wide number of stations.

(2) Study of the regular daily variations of the geomagnetic field caused by the sun and the moon, particularly close to the *magnetic and geographic equator* and to understand these in the light of solar radiation absorbed in the upper atmosphere and of the motions at these heights.

(3) Determination by means of rockets of the location and the study of equatorial electrojets believed to be responsible for large magnetic disturbances.

One of the primary concerns was to see that the pre-IGY network of geomagnetic stations was extended to cover the critically important zones.

These included: (a) the two polar caps (including the auroral zones) and (b) the equatorial belt.

The primary target for India was the study of the "equatorial electrojet", the extent and variability of the electrojet belt ($\pm 5^\circ$ of the geomagnetic equator) and of relating these with the location and nature (height, thickness, current density) of current systems in the upper atmosphere. It was clear that to understand the latter one must carry specially-designed light weight magnetometers with rockets to heights into the upper atmosphere. This was done very extensively by Cahill (1959) from several locations in the equatorial region, in the vicinity of the Line Island using rockoons and specially designed proton precession magnetometers. Such attempts were to be made later in India by Sastry in collaboration with Cahill, but during the IGY all measurements in India were conducted with groundbased instruments and prinicipally by the India Meteorological Department and Geodetic and Research Branch of the Survey of India in Dehradun. The most important effort was the setting up of a close network of geomagnetic stations near the geomagnetic equator at Alibag, Kodaikanal, Annamalainagar (gm 1°26'N); and Trivandrum (gm 0°53'S); the last two stations were started specially for the IGY programme. Both started functioning from September 1957. The observatory at Alibag (9°30'N gm), although outside the field of the electrojet, formed an extremely useful reference for study at the lower latitudes, in view of its long series of uninterupted observations since 1904. Annamalainagar and Trivandrum served as station doublets close to the geomagnetic equator and on two sides of it.

The Geodetic & Research Branch of the Survey of India, Dehra Dun also took a major role. This Department had a long history of geomagnetic measurements since 1901 at several well chosen and evenly distributed repeat stations. The objective was to determine the annual changes in the magnetic elements for reducing the results of the survey to a common epoch.

During the IGY these activities were intensified and during the field seasons 1957-58 and 1958-59 absolute magnetic observations for the dip, horizontal force and declination were taken at 60 repeat stations spread all over India. Some new repeat stations were added on the geomagnetic equator on east and west coasts of India. In addition observations for horizontal force, declination and vertical force anomalies were taken at a number of field stations en route to repeat stations. The instruments used were calibrated at Alibag Observatory against their standard instruments by simultaneous observations.

4.3 Aurora and Airglow

The high atmosphere emits light observable at night and during twilight of two distinct kinds. One of these, called the aurora (caused by impact of

solar energetic particles with the upper atmosphere) is generally visible in magnetic latitudes at about 60° and more, but may extend down to equatorial latitudes during great magnetic and ionospheric storms. The programme for aurora has been briefly reported in Section 3.1. No auroras were recorded by the ten visual stations set up by the IMD during IGY or IGC ; the only aurora reported was by an Indian ship outside the Indian subcontinent. Several outstanding tropical auroras had been listed by Chapman (1957); one of the greatest auroras on record occurred on September 11, 1959. Another occurred on February 4, 1872: the latter was seen from Bombay (Figure 9) (19°N gg; 10°N gm) and from seven other places in India. This aurora was accompanied by an outstanding magnetic storm. Other outstanding tropical auroras were observed on September 25, 1909 (an intense magnetic storm occurred) and the aurora was seen in Singapore (1°N gg, 10° Sgm) ; on May 13, 1921 (observed from Samoa, 14°S gg ; 16°Sgm) and from Tongatabu, (21°S gg, 23°S gm). Other tropical auroras that may have been missed (or not recorded) should be looked for around the following list of the twelve greatest magnetic storms recorded at Greenwich during the period 1874-1954.

1882	Nov., 17, 30	1940	March 24
1903	Oct., 31	1941	March 1
1909	Sept., 25	1941	Sept 18
1921	May, 13		
1938	Jan., 25	1946	March 18
1938	April, 16	1946	Sept 21

Low latitude auroras have short durations, generally not more than 12 hrs, and the favourable observation condition occurrs when the increase period of accompanying storm coincides with the night period of the observatory. The 1872 February aurora was seen in Bombay from 2300 hrs to sunrise.

For airglow, Indian programme was extensive. There were several active groups : one at Poona under Chiplonkar and the other at Ahmedabad under Ramanathan. The programme evolved around the activities of these two institutions—the objective was to understand the temporal and geographical variation of intensity of night airglow at a number of wavelengths. There were two main projects: photometric and spectroscopic. The photometric observations recommended the following priority: 5577Å, 5893Å, 6300Å, OH bands. The observating stations were at Mt. Abu recordings (5577 Å and 6300 Å ; PRL). Photometric observations were also initiated at Srinagar at 5577 Å.

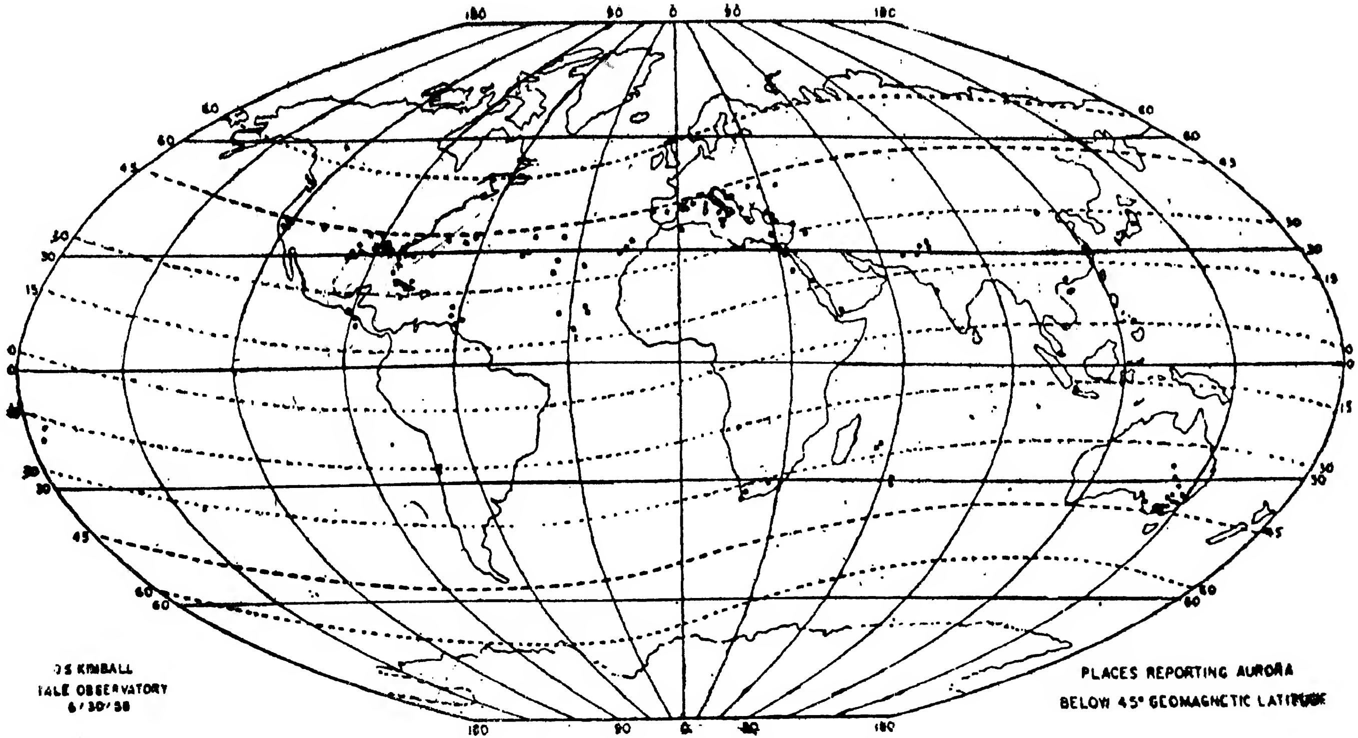


Figure 9. Part of the globe, showing 0° 30° and 60° circles of geographic (gg) and geomagnetic (gm) latitude, also 45° (gm), Dots indicate places in the minauroral belt (extending between N and S circles of gm latitude 45°) for which observation of aurora has been recorded (courtesy: D. S. Kimball, *Annals of IGY*.

The photomultiplier photometer at Mt. Abu was calibrated against Roach's Fritz Peak portable photometer which he brought with him.

At the time of the IGY, airglow measurements were made from the ground and the principal interest was to understand the mechanisms of emission, the atmospheric levels involved, and from the morphological features to derive dynamical and chemical properties of the atmospheric levels.

4.4 Ionosphere

The Ionospheric programme was the most extensive. A special feature was the establishment of a network of eleven stations, that spanned over a wide range of latitudes (from 28°38′N to 08°29′N), but centred primarily around 75°E longitude zone. These studied the characteristics of the earth's ionosphere with almost all major techniques included in the international programme. Of these eleven stations, five (Waltair, Madras, Tiruchirapalli, Kodaikanal and Trivandrum) fell in the anomalous equatorial zone (Appleton anomaly belt) bounded by $\pm$ 30° dip values (see Figure 6). Of great importance was the relative position of Kodaikanal and Trivandrum. Trivandrum was as much south of the geomagnetic equator as Kodaikanal was north. It was established especially for the IGY.

(i) *Vertical Incidence Soundings*: Before the IGY, India had seven vertical incidence soundings stations, at Delhi, Madras, Tiruchirapalli, Ahmedabad, Calcutta, Kodaikanal and Bombay. Of these, Ahmedabad, Calcutta (Haringhata), and Kodaikanal had automatic stations: the rest were manual. While 24 hours observations were available for the automatic stations, the data for the manual stations were more restricted, usually covering only daytime observations.

Indian IGY plans called for round-the-clock observations for all the seven stations and the establishment of a new station at Trivandrum at the magnetic equator under All India Radio. The station at Trivandrum was initiated in January 1957.

The distribution of Indian stations had a special significance. Most of these were located within the equatorial zone defined by $20°N > \phi > 0°$. There existed three main chains of equatorial stations. These were the Indian, South American and African chains, lying roughly around 75°E, 75°W and 0° longitude zones respectively. The stations are listed in Table 4.

The Radio Propagation Unit at the NPL was the coordinating and monitoring organization. The usual channel of publication, "Ionospheric Data" series of this Unit, was continued.

Table 4

Indian Chain (75°E Zone)	African Chain (0° Zone)	South American Chain (75°W Zone)
Delhi	Ibadan (Nigeria)	Bogota (Columbia) Pasto (Columbia)
Banaras	Enugu (Nigeria)	Guyaquil (Ecuador) Talara (Peru)
Ahmedabad	Kumasi (Ghana)	Chiclayo (Peru) Chimbote (Peru)
*Calcutta	Little Legon (Ghana)	Arequippa (Peru) Cuzco (Peru)
Bombay	Accra (Ghana)	Huancayo (Peru) Trujillo (Peru)
Poona		Antofagasta (Chile)
Waltair		
Madras		
Tiruchirapalli		
Kodaikanal		
Trivandrum		

*Calcutta, 90°E Zone.

At this Unit, a C4 Ionospheric recorder was installed in April 1958. This was in addition to the ionospheric recorder in regular operation at A.I.R., New Delhi. This new recorder was used for special studies, such as true height analysis, sunrise effect and dynamic effects. The recorder was run at half hour intervals on normal days and at more frequent intervals during solar flares.

(ii) *Ionospheric Drift Measurement*: Before the IGY, ionospheric drift measurements were being made at Ahmedabad, Delhi and Waltair. Observations at all these stations were continued. An additional station was planned for the IGY at Haringhata, but this did not materialise.

At Ahmedabad measurements were made on 2.4 and 4.0 MHz using vertical pulse transmission and three-station reception. On World Days observations are made in the night hours also. Observations at 6 MHz were started on March, 1958.

At Waltair observations were made on frequencies of 2 MHz and 6 MHz on all the Regular World Days and during the SWI. There was occasional gap of data on certain days around noon due to high absorption. At AIR, Delhi, observations were taken hourly at frequencies of 2.5 and about 6.0 MHz on all World Days and SWI, and every 3 hours twice a week on other days.

(iii) *Absorption Measurements* : In the beginning of the IGY, ionospheric absorption measurements involving pulse transmission were in progress at Delhi (AIR) and Ahmedabad. At the latter, measurements by cosmic noise method were also in progress. These observations were continued.

During the IGY it was planned to establish additional cosmic noise stations at Delhi (NPL) and Madras, and an additional pulse stations at Haringhata and Madras. The first two stations were established. At NPL, observations were initiated at 22.4 MHz during 1957 and were later changed to 30 MHz from February, 1958. At Madras cosmic noise observations were initiated ot 20 MHz and pulse measurements at 2.2 MHz.

(iv) *Atmospheric Terrestrial Noise Studies:* Indian plans under this programme called for sferics measurements at the India Meteorological Department stations at Delhi and Calcutta and waveform studies at Banaras and Poona. This programme was fully implemented.

An additional project since added to the Indian programme concerns continuous flare patrol at 27 KHz and 100 KHz at NPL, New Delhi.

4.5 Solar Activity

For keeping a 24 hour watch on the sun, India's position was a critical one. The sun was watched by both optical and ratio methods. The optical observations were made by: (1) the Astrophysical Observotory, Kodaikanal and (2) Nizamiah Observatory, Hyderabad. Radio observations were carried out at a number of places including: (1) National Physical Laboratory at New Delhi (2) Physical Research Laboratory at Ahmedabad (3) Nizamiah Observatory, Hyderabad and (4) Astrophysical Observatory, Kodaikanal.

4.5.1 *Optical Observations*

(a) *Kodaikanal Astrophysical Observatory*: The Astrophysical Observatory at Kodaikanal, near the geomagnetic equator, made visual, optical and spectrophotographic observations of solar phenomena such as sun-

spots, solar prominences and solar flares. The normal routine programme of observations was extended as below:

Photoheliograms: A photoheliogram in the blue-violet region was taken every day in the morning using a 15 cm. photoheliograph, and, weather permitting, two more times one at about 0500 hrs UT and the other at 0830 hrs UT on smaller plates, but covering the sunspot belts. In addition, visual sketchings were taken of spots and faculae once every day.

Prominence Spectroscope Observations: Visual observations of fairly tall prominences in $H\alpha$, D_3 and $H\beta$ lines were made with the prominence spectroscope once a day. Flares, dark-markings, sunspots etc., were also studied.

Spectroheliograms: Two complete sets of spectroheliogram of the disc in $H\alpha$ and K and the prominence in K were taken daily at about 0200 hrs UT. In addition, two more sets of spectroheliograms were taken, one at about 0600 hrs UT and the other at 0830 hrs UT. Photometric standards were impressed on all these spectroheliograms.

Spectrohelioscope: Prominences, flares, dark markings etc, were visually observed in the $H\alpha$ line with the spectrohelioscope. The hours of watch were 0200-0300, 0400-0430, 0500-0530, 0600-0630, 0830-0900 and 1000-1030 hrs UT. A series of measurements of the effective line width, intensity, area, etc., were made at frequent intervals according to instructions contained in the Instruction Manual of Solar Activity.

To the spectrophelioscope of the Kodaikanal Observatory was attached a camera which permitted photographing of the spectra of prominences, flares, etc., along with visual observations. The third order spectrum covering almost the entire region from the H and K lines to a little beyond the F line could be photographed with this camera on a scale of about 3A/mm; simultaneously H-alpha line of the second order could also be photographed on a strip of plate sensitive to the H-alpha line. Spectra of flares, eruptive prominences, etc., were photographed with this camera at frequent intervals during the progress of the phenomena. Special arrangements also existed for impressing photometric standards on the spectrum plates.

Lyot Heliograph & Coronograph: The installations of the large (20 cm aperture) Lyot Coronograph, the Lyot monochromatic Filter (band-pass 0.65 Å) and the large solar telescope (consisting of a celeostat with three fused silica mirrors of 60 cm aperture and the telescope objective of 36 metre and 18 metre focal lengths) and the large spectrograph to work with the telescope were completed.

Though the optical components of the instruments were imported, the instruments themselves were assembled in the workshop of Kodaikanal Observatory. The heliograph and coronograph were installed in separate domes; the one for the coronograph was specially constructed. Observations of the sun with these instruments were started from 1959. With the addition of these new instruments, Kodaikanal Observatory ranked amongst one of the few well equipped observations for advanced solar work.

Nizamia Observatory: This observatory participated in the observations of (i) solar flares, (ii) bright and dark surges and active prominence regions and (iii) sudden disappearance of filaments and prominences. These were observed by means of a spectrohelioscope in $H\alpha$ light. The patrol hours of this observatory were 0300-0400, 0430-0500, 0530-0600, 0900-1000 and 1030-1100 hrs UT.

4.5.2 Radio Observations

(a) National Physical Laboratory

Radio Patrol of solar flares was kept in this laboratory for the major period of the IGY and the IGC, using three different techniques:

(i) Sudden Enhancement of Atmospherics (SEA) at 27 and 100 KHz.

(ii) Sudden Cosmic Noise Absorption (SCNA) at 22.4 and 30 MHz.

(iii) Fast observations made by a C-4 automatic ionospheric recorder, sweeping over 1-25 MHz.

The three techniques, when simultaneously used, covered a wide frequency range from 27 KHz to 30 MHz and, therefore, permited for the first time, a reliable study of the frequency dependence of the ionospheric flare effect.

(b) Physical Research Laboratory, Ahmedabad

SCNA was recorded over the entire period of the IGY and IGC at a frequency of 25 MHz.

(c) Nizamia Observatory, Hyderabad

Observations were made of both SCNA and of enhanced radio emission from the sun at a frequency of 30 MHz (Krishnamurthi, 1958)

(d) Research Department, AIR

Sudden changes in the field intensity of Tashkant Radio station received at Delhi at 164 KHz wae found to be a sensitive index of solar flare.

(e) Kodaikonal Observatory

Radio flux measurements with two yagi antennas were being monitored as Kodaikanal at 100 and 200 MHz (Annual report of Kadaikanal Gbservatory).

4.6 Cosmic Rays

The international programme on cosmic rays covered:

(i) A study of the relationship of cosmic ray intensity with solar actvity, with geomagnetism, with lunar and solar atmospheric variation, with atmospheric ozone.

(ii) A study of the anisotropy of the primary cosmic radiation and the determination of the composition of the mass spectrum and the energy spectrum as a function of geomagnetic latitude. The geomagnetic field acts on cosmic rays as a convenient mass or momentum spectrometer, and this makes it possible to select particles according to energy or magnetic rigidity.

(iii) Atmospheric influence on cosmic radiation (mass absorption, effect of temperature on the production of mesons and the effect of atmospheric tides on their intensity.)

(iv) Investigation of soft cosmic radiation emitted by the sun during solar flares.

CSAGI further recommended that standardised equipments should be used as far as practicable and, in particular, recommended a standard counter telescope design to detect the cosmic ray intensity at relatively high energies, and a standard neutron monitor pile for observations of the low energy portion of the cosmic ray spectrum.

The Indian programme covered a substantial portion of the international recommendations. The network was as follows:

Gulmarg	Cubical meson telescope
Darjeeling	Cubical meson telescope
Ahmedabad	Cubical meson telescope neutron monitor
Howrah	Ionization chamber
Kodaikanal	Cubical meson telescope neutron monitor

4.7 Latitudes and Longitudes

Before the IGY there had been two worldwide determinations of latitudes and longitudes of major astronomical observatories, the latter being in 1933. Since then there had been new instrumentations for determination of time and latitude including availability of quartz clocks at the astronomical observatories. This had allowed more precise determination of the irregularities in the earth's rotation. There were several known type of variations of the rate of rotation of the earth: (i) seasonal, believed to be associated with seasonal variations in the angular momentum carried by the winds, (ii) slow variations of an irregular or secular nature. During the IGY a number of astronomical observatories were equipped with special moon cameras with which the position of the moon relative to the background of the stars could be accurately determined. Atomic frequency standards also provided a close check on the performance of the quartz crystal clocks.

The Indian programme on latitudes and longitudes was conducted principally by the following organisations:

(i) Geodetic and Research Branch, Survey of India, Dehra Dun (Latitudes and Longitudes)

(ii) U.P. State Observatory, Nainital (Photographic Observations of the moon's position by Marcowitz moon camera)

(iii) National Physical Laboratory: establishment and operation of a Standards Frequency and Time Service.

4.7.1 Survey of India

The Survey of India Observatory at Dehra Dun, which carried out the major portion of the Indian Programme in this discipline participated also in 1926 and 1933 international Longitude Projects. This was the third operation of World Longitudes. During the IGY, simultaneous observations were also taken of latitudes. The duration of these observations covered a time interval of at least 430 days (i.e. a Chandler period).

Observations were carried out according to specified international procedures. Three transit instruments, one of them fitted with Hunter's Shutter, were used for time observations and a Zenith Telescope and Wild T_4 for latitude observations. The Danjon's Impersonal Astrolabe was acquired during the IGY, but could not be used because of damage in transit.

In the reduction, use was made of the same Fundamental Catalogue FK3 and its supplement as corrected by Kopff. For longitude operation, use was made of time signals of the classical type in the absence of quartz

clocks and automatic recording of WWV-type signals. Propagation time as supplied by Bureau International de l' Heure (B.I.H.) was used in the final reduction of longitudes, and corrections were effected for refraction using observed data on temperature and wind. The results of time observations were transmitted to the B.I.H. The normal work of the B.I.H. consists in determining the definitive time in terms of the Universal Time (U.T.) from the collective results of the various time services. The system of time that was used, commencing from 1st January, 1956 was the Universal Time corrected for seasonal irregularity of the earth and for the influence of the polar motion. This system of time is called UT2. The corrections necessary for taking account of the seasonal irregularity in the rotation of the earth and of the motion of the pole were provided by the B.I.H.

Whereas most of the information needed for the observation continuing upto 31st December 1958 was regularly sent to the B.I.H., the final longitudes were later reduced at Dehra Dun itself as the definitive corrections to radio time signals were published by the B.I.H. The values of longitudes obtained on previous occasions were not quite the same as seen below:

	h	m	s
1894-96	5	12	11.77
1926	5	12	11.75
1931	5	12	11.78

the 1894-96 value being generally accepted. It was expected to establish a really reliable value of longitude for Dehra Dun from the IGY observations.

4.7.2 Latitudes

Talcott's method with Zenith Telescope, as used by the International Latitude Service for the preceeding 60 years, was employed in the observations at Dehra Dun. For the latitude of Dehra Dun and its weather conditions, it was not possible to arrange observations in more than six groups. About eight pairs of stars were taken to make one group and at least two groups were observed each night, a third group observed during period of bad weather.

Generally the two group means of co-latitude for the same methods of observations were not the same and the differences were attributed to residual declination errors of the groups.

The mean latitude as determined by Orlov's formula from the corrected values of latitude was obtiened as 30°—18′—51″.759.

4.7.3 Photographic Observation of the Moon's Position by Markowitz Moon Camera at Nainital

The Markowitz moon camera specially organised for the IGY, is a special dual-rate camera, designed by Markowitz of U.S. Naval Observatory, which holds the moon fixed relative to the stars during a simultaneous time exposure by means of central dark filter which tilts (Figure 10).

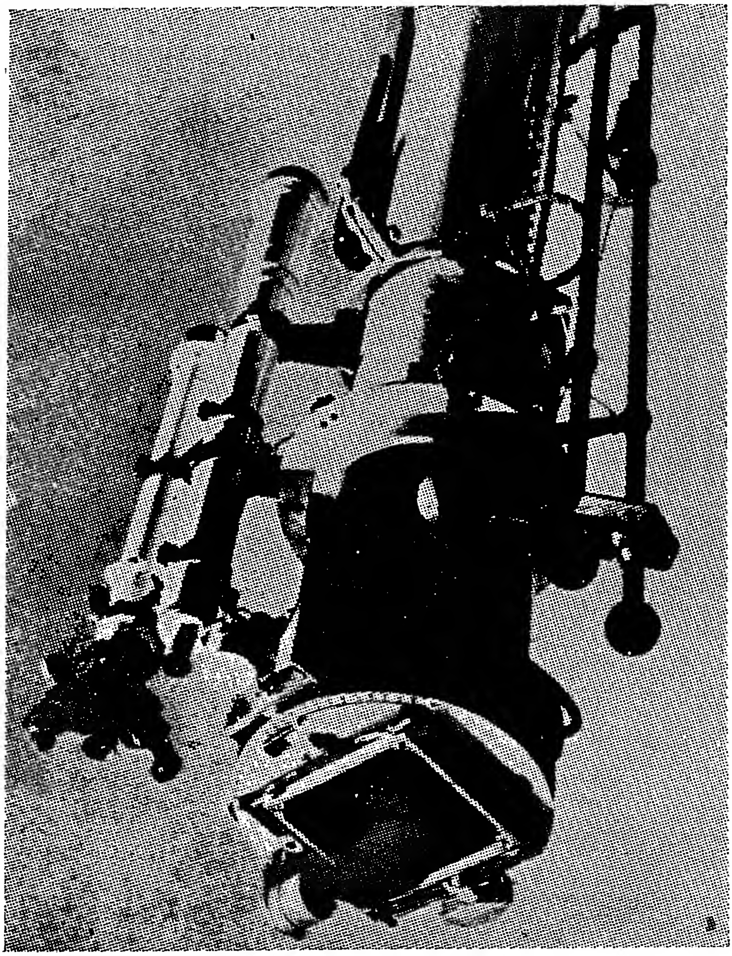


Figure 10. View of the Marcowitz moon camera attached to the 10″ refractor (Source: *JSIR Vol. 17A, 1958*).

Twenty such cameras were built by U.S. Naval Observatory of which one was installed at Nainital (Bappu, 1958). The probable error of a single

observation was about 1.5 second of arc corresponding to about 900 ft. on earth. With a chain of 20 observatories it was expected to reduce uncertainities in the distance between continents to about 90 ft. against the then existing accuracy of 200-300 ft (as much as a mile for some islands). The technique also added greatly to the precision with which changes in the speed of rotation of the earth could be measured, with consequent new information.

The camera reached Naini Tal in the last week of December 1957. The 10-inch Cooke refractor was immediately assigned to the project, went through accurate polar adjustment to within a minute of arc; the camera was then installed on the telescope after carrying out the modification required on the telescope. Regular operation was commenced in the first week of June, 1858. Photographs of the moon began to be taken and the plates shipped to the measuring centre.

4.7.4 Frequency and Time Standards at NPL New Delhi

A standard frequency station was established in the NPL, New Delhi. The relevant characteristics were as follows:

Primary standards used	:	Three Essen Ring type crystals
Station	:	Kalkaji (28°33′36″N, 77°18′48″E)
Call sign	:	ATA
Emissions (hours per day)	:	Two
Emissions (day per week)	:	Seven
Standard frequency being used as a carrier	:	10 MHz
Standard modulation frequency	:	1000Hz
Duration of the time signals in the transmission cycle	:	Continuous
Method of adjusting the time signals	:	By steps of 50 milliseconds
Transmission cycle per hour	:	(a) 1000 Hz modulation with carrier for the periods 0-4, 15-19 and 45-59 min.;
		(b) Pure unmodulation R.F. for 4-14, 19-29 and 45-59 min.;

(c) voice code announcements of 30 sec duration during the periods 14-15, 29-30, 44-45 and 59-60 min.; and

(d) no transmission during the period 30-45 min. enery hr.

4.8 Glaciology

The Geological Survey of India undertook glaciological studies in the Himalayas during the summers of 1956, 1957 and 1958.

The main aim was to observe and record the changes in the glaciers with respect to earlier observations. In certain areas mapping was made on 1″ to 200 feet scale or larger and cairn marks were set up. Observations included: type of glacier, gradient, direction of flow and velocity along the horizontal and vertical plane of the glacier, length and total areas of glacier, area of accumulation and ablation, snow and firm lines, indications of advance or retreat based on previous observations or morphological evidence, temperature distribution; morphological character, snow feature etc.

4.9 Oceanography

The following programme of oceanographic observations was recommended:

(1) Origin and propagation of long-period oscillations of the sea surface (tidal waves, storm tides and oscillations of longer periods caused by seasonal variations in temperature and winds)

(2) water temperature down to 200 m wherever there was a sufficiently dense network of weather observations

(3) water circulation, waves swell, sediments and the structure of the earth's crust along two north-south lines passing through the equatorial regions

(4) Speed, temperature and salinity of the water and of air/water heat exchanges

(5) Movement of the line of separation between the temperate and Arctic waters and of the warming of the Arctic.

4.9.1 Survey of India

The Geodetic and Research Branch of the Survey of India carried out some of the oceanographic observations.

The object was the investigation and understanding of the following, among other subjects:

(i) Seismic and storm surge

(ii) Slower change in level, such as may be caused by seasonal changes in temperature and wind.

(iii) Oceanic circulations.

The main tasks consisted of:

(a) Shore stations

Recording of:

(i) Sea level variations

(ii) Long period waves

(iii) Meteorological observations

(b) Afloat

(i) Depth, temperature, salinity and chemical analysis

(ii) Colour and transparancy

(iii) State of sea and swell

(iv) Currents and tidal streams

(v) Bottom sediments

(vi) Bathysmetry

(vii) Meteorology and actinometry

(viii) Bathy-thermography

(ix) Biology.

Monthly mean sea levels were computed from the hourly readings of tides from the records of automatic tide-gauges operating at Aden, Mundra, Kandla, Veraval, Bombay (Apollo Bundar), Ratnagiri, Mangalore, Madras, Visakhapatnam, Calcutta (Garden Reach), Port Blair, Cochin, Saugor, Diamond Harbour and Rangoon.

Short period tidal observations (31 days) round the clock at half hourly intervals, of water level on tide pole at Kotra, Jafarabad, Bedi, Trivandrum, Aleppey, Kolachel, Tuticorin, Pamban and Nagapatnam were carried out for studies of tidal regimes.

Tidal streams observations (of 1-2 days duration), with current meters and logship, were carried out at 60 sites in the Gulf of Cambay for studies of tidal flows and with a view to prepare an atlas of Indian waters depicting tidal streams and currents at all stages of tides.

Surface water temperature and salinity observations were compiled from the data supplied by the port authorities at Kandla, Mangalore, Cochin, Mandapam, Madras and Waltair (Palm Beach); other meteoro-

logical observations (e.g. direction and speed of wind, surface air pressure and temperature etc. observed at fixed hours) from the port authrities or Indian Meteorological Deptt., at Mandvi, Kandla, Veraval, Colaba, Ratnagiri, Mangalore, Cochin, Madras, Alipur, Palm Beach, Waltair, Visakhapatnam, Port Blair, Ernakulam, Karwar, Calicut, Palk Bay and Mandapam; data of Aden at 0h, and 6h G.M.T. from the Overseas Weather Bulletins.

4.9.2 India Meteorological Department

In a coordinated study of the storm surges at sea, meteorological observations were organised at harbours equipped with automatic tide stations and data of wind pressure and temperature at the times of high and low water wave recorded.

4.10 Rockets and Satellites

While rockets as a tool of upper atmospheric research dated from pre-IGY era, satellite was uniquely an IGY achievement. The first satellite, Sputnik I (1957α) was launched on October 4, 1957, a few months after the IGY began, and was a part of the USSR programme of IGY.

The satellite programme arose from a resolution of the special committee of the IGY (October 4, 1954), which read:

"In view of the great importance of observations during extended periods of time of extraterrestrial radiations and geophysical phenomena in the upper atmosphere, and in view of the advanced state of present rocket techniques CSAGI recommends that thought be given to the launching of small satellite vechicles, to their scientific instrumentation, and to the new problems associated with satellite experiments such as power supply, telemetering and orientation of the vehicle".

Following this resolution, two nations agreed to undertake the the responsibility for launching the satellites. However, while launching was predominantly the concern of these two countries, for accurate tracking of the satellites, it was necessary to enlist the cooperation from other nations including India. India's participation was of particular importance, as it filled an important gap between Japan and Iran for the precision optical network.

The Indian contribution to the satellite programme was the setting up of a Baker-Nunn camera at Nainital and the beginning of work on atmospheric modelling from satellite drag observations.

4.10.1 Precision Optical Tracking Programme at Nainital

The Baker-Nunn Camera (one of world's twelve) installed at the U.P. State Observatory at Nainital had been loaned by the Smithsonian Institute Washington (Fig. 11,12). It utilised a 20-inch apochromatic three-element

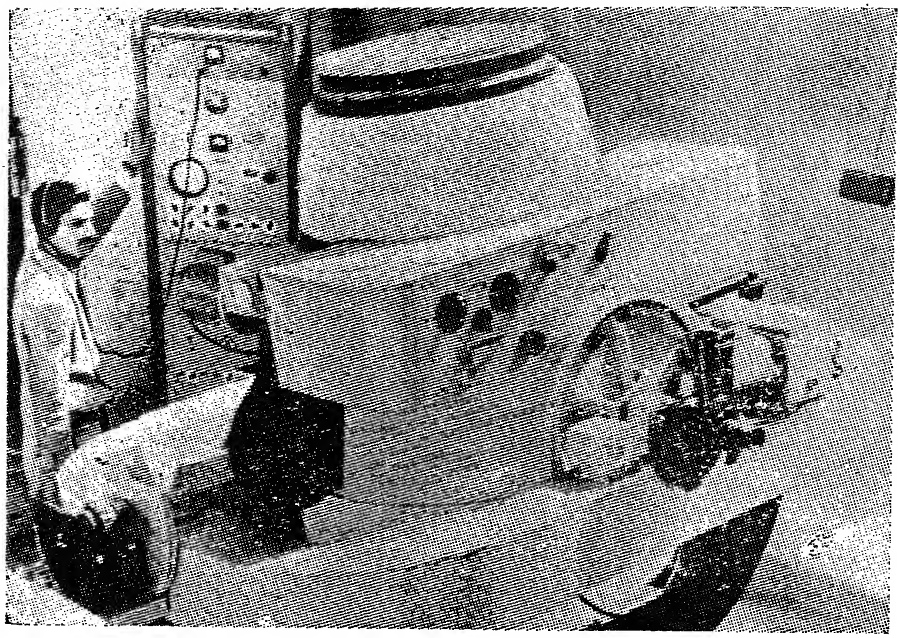


Figure 11. The Baker-Nunn camera at Nainital (Source: *JSIR, Vol 17*A *1958*).

Figure 12. Photograph of satellite obtained with Baker-Nunn camera (Source: *JSIR, Vol. 17A 1958*).

corrector plate and a 31 inch spherical mirror. The instrument could photograph rapidly moving satellites as faint as the 13th magnitude. The measuring accuracy was 2 seconds of arc. The camera arrived at Nainital in April 1958 and was installed by the end of June, 1958. The camera has been in operation since then. Tracking was assisted by the availability of a very rapid communication facility between the computing centre at Cambridge (USA) and Nainital for it was necessary to have advance information on azimuth, altitude, angular velocity and the expected instant of culmination of the satellite at the station. The epoch and B.D. positions of successful observations were cabled to Cambridge within a few hours after transit.

4.10.2 Radio Observations

Radio Observations of satellites were made principally by the following organisations in India :

1. National Physical Laboratory, New Delhi.
2. All India Radio, New Delhi.
3. Wireless Planning and Coordination, New Delhi.
4. Ministry of Defence, New Delhi.
5. Overseas Communication Service.

Radio observations recorded principally the time of transit and duration, amplitudes of transmitted signals and doppler changes in frequency.

At the National Physical Laboratory a programme was undertaken to develop models of atmospheric density, pressure and temperature for the high atmosphere and outer space and related topics from data obtained by U.S. and USSR satellites. An atmospheric model was prepared (Mathur and Mitra, 1960).

4.11 Seismology

The main object of the programme was to collect seismological data from the worldwide network of existing seismological observatories and from new observotories specially opened during the IGY. The idea was to have special studies in the determination of the precise shape of figure of the earth, on earth tides, seismicity and structure of the crust of the earth, mantle and interior of the earth, and other related problems. A special

feature was the opening of seismic stations in the Arctic and Antaractic regions, information from which was hitherto lacking.

India's programme of work in this discipline consisted of the maintenance of the network of seismological observatories existing at the beginning of the IGY and the opening of *two new stations*. The stations existing at that time were (1) Shillong, (2) Bombay, (3) New Delhi, (4) Calcutta, (5) Kodaikanal, (6) Poona, (7) Dehra Dun, (8) Tocklai (Assam), (9) Bokaro, (Bihar) and (10) Madras and were controlled by I.M.D.

In addition to these, the seismological stations at Hyderabad, Vizianagram and Chatra, operated by State Governments, continued to function uninterruptedly.

The new stations opened were at Port Blair and Agra. Both had special significance. The Port Blair observatory started functioning from April 1957; that at Agra from December 1957. Agra was equipped with a specially designed long-period seismograph loaned by Lamont Geological Observatory of the USA. It had an unusually large period of 15 sec and was coupled to galvanometers of periods of the order of 100 sec and was thus specially sensitive for recording very long wavelengths. Similar instruments were also loaned to a few other countries to provide global coverage. The specific objective was the study of structure of the earth's crust from Raleigh and Love waves. Such instruments in the past had revealed the presence of surface waves having periods of the order of several minutes in records of major earthquakes.

The nature and origin of microseisms having periods of 2-10 sec and studied for the last 3 decades, also received special attention, since the exact cause of their origin was not understood. An important aspect was its possible application in the tracking of storms at sea.

Before the IGY, seismograph stations at Madras, Bombay, and Shillong were equipped with sensitive microseismographs. These were standardised and were maintained continuously during the IGY. The additional new station at Port Blair (equipped with a standardised Sprengnether type microseismograph) offered possibility of study of storms observed frequenlty in the Bay of Bengal originating near the Andamans. The seismograph stations at (1) Howrah, run by the Bengal Engineering College and (2) Cochin, operated by the Naval Physical Observatory also cooperated.

4.12 Gravimetry

The gravimetric activities, conducted principally by the Survey of India, consisted of :

(a) Observations of earth tides at eight different stations in India (Dehra Dun, Ootacamund, Gummidipundi and New Delhi for 1957-58 and Pathankot, Bombay, Shillong and Lakhnadon during 1958-59)

(b) Gravimetric observations at about 1200 stations in Central India and reduction of gravity anomalies for about 500 stations.

(c) Gravimetric connection between the World First. Order Gravity station at New Delhi and the National Reference Station at Dehra Dun.

The details of the programme were as follows:

Earthtide observations consisted of visual gravimetric readings with two different precision gravimeters every half hour for 31 consecutive days at each station, alongwith temperature and pressure recordings. The eight stations were selected from considerations of geology, gravity abnormalities and varying distances from the sea.

In regard to gravimetric observations, during the season 1957-58 observations to extend the projected 10 mile gravity net of India could not be undertaken. However, during season 1958-59, a Geodetic Worden gravimeter was spared for this work and a dense net of about 1200 gravimetric stations was established in Central India as part of a project, requiring about 4000 stations, surrounding the National Geodetic origin of Kalianpur H.S. and a few neighbouring astrogeodetic stations in order to obtain data for the determination of the gravimetric deflections of the plumb-line.

The International Gravimetric Commission had recommended establishment of a firm gravimetric connection between the World First Order Gravity station at New Delhi and four neighbouring stations of the 1st Order net: Beirut, Khartoum, Tokyo and Singapore. There was also a recommendation of an early gravimetric connection between the National Reference Station (Dehra Dun for India) and a First order station in the neighbourhood. The former project could not be undertaken during the I.G.Y. but the latter was implemented. Although the connections between the Indian First Order Station at New Delhi and the National Reference Station of Dehra Dun had previously been done on a few occasions, these were not sufficiently reliable. Consequently a priority effort was devoted to accurate connections with three different precision gravimeters between these two stations by proceeding in stages and making small

loop circuits between intermediate stations, thus reducing drift uncertainties.

4.13 Nuclear Radiation

The nuclear radiation programme included measurement of radioactivity in the atmosphere and the deposition of radioactivity on the ground. Atmospheric radioactivity consists of natural radon and thoron and their decay products, and radioactive fallout from the testing of nuclear weapons. Measurements over an adequately distributed global network were expected to provide information on large scale movement of air masses: information considered useful in evaluating health hazards of radioactivity originating from testing of nuclear weapons.

In India the programme was carried out by the Atomic Energy Establishment, Trombay, where such programme was already in progress.

The following measurements were carried out:

(i) Measurement of particulate airborne fission products at ground level : These were carried out at seven stations: Bangalore, Bombay, Calcutta, Delhi, Nagpur, Ootacamund and Srinagar. Hollingsworth and Vose type H-70 filter paper of 1" effective diameter was used for the collection of particulate matter from the air and the activity was measured with an end mica-window G.M. counter calibrated with a standard potassium chloride source after a lapse of 72 hours to allow decay of natural radioactivity.

(ii) Measurement of the deposition of fission products activity on the ground: These were also carried out at the above seven stations. The samples of deposited activity were collected in stainless steel pots 30 cm in diameter and 45 cm high. The pots were exposed to the free atmosphere 3 ft. above the ground. The collection period for each sample for counting the collected rainwater and dust were evaporated and the residue was transferred to a perspex planchet. Some of the samples were also analysed for Sr 90 and Cs 137.

(iii) Library of rainwater samples: A library of rainwater samples collected from the seven stations during the rainy months of 1959 was maintained. These samples were collected for measurements of : tritium, other long-lived radioactive isotopes, analysis of O_{16}/O_{18} and H/D ratios, and precipitation chemistry.

5. Achievements of the IGY

Perhaps the single most important event of the IGY was the launching of satellites and with it came a revolution in our concept of atmospheric environment, of radiation interacting with this environment, the discovery of the magnetosphere and the radiation belt, a new description of the geoid and several other major changes in our concept of the earth. These are discussed briefly in the context of the Indian contributions.

Before the IGY, our knowledge of the Upper Atmosphere that could be inferred from ground-based measurements was limited to about 200 km. for the neutral atmosphere, and to about 300 km for the ionized atmosphere. It was believed that the earth and the sun, although interacting with each other, are completely separate bodies with nothing but essentially empty space between them. It was further believed that the magnetic fields of the earth and the sun each exerted a controlling influence on the ionized gases in its own neighbourhood only. The influence of the sun on the earth's atmosphere was considered to occur mainly through photon radiation and occasionally through bursts of charged particles that impinge on the earth's atmosphere to produce storms in the ionosphere accompained by magnetic irregularities and aurorae.

The IGY changed this picture drastically. With satellites continuously monitoring the interplanetary space and its magnetic fields the earth was found to be immersed in a stream of charged particles flowing steadily outwards from the sun. This solar wind distorts the sun's magnetic field and pulls it out along the radial direction. The interaction of the solar wind with geomagnetic field produces a bow shock upstream in the wind from the obstruction presented by the geomagnetic field, distorts the earth's magnetic field in a comet shaped region called the "*magnetosphere*" and stretches out the geomagnetic line of force behind the earth to form an extended tail or wake. In parts of it charged particles can oscillate back and forth trapped by geomagnetic lines of force, and particles from the solar wind can enter these trapping regions in ways not then fully understood. During a solar disturbance additional bursts of charged particles emitted from active areas of the sun are superimposed on the normal solar wind. These further distort the solar magnetic field and dump the particles already trapped in the trapping regions into the ionosphere to produce the aurora and the magnetic storms.

The second major difference was an extension of the classical ionosphere. We used to believe that the ionosphere begins around 60 km and ends around 600 km. Observations with whistlers showed that ionization extends to distance of several earth radii. We have, therefore, a continuous transition from the earth's ionosphere into the magnetosphere.

The third major difference was the realisation of the critical role played by chemical reactions in the near-vacuum conditions of the upper atmosphere. These are not merely confined to emissions from excited species which generate the aurora or the night sky emission (a major target area for the IGY) but produce a number of new constituents both ionized and neutral. One of the most startling conclusion reached was that some of the minor constituents which are no more than a millionth or less of the total atmosphere often play the major role in the upper atmosphere. Examples are ozone, nitric oxide and water vapour: nitric oxide particularly, as its effect was found to be crucial over a large range of the ionosphere from 60 km to the F region.

5.1 The Neutral Atmosphere

At the beginning of the IGY the density and the temperature of the neutral atmosphere were relatively well known below 100 km and with less precision up to 200 km. The experimental measurements came from use of: (i) balloons, (ii) anomalous propagation of sound from surface explosions, (iii) meteors, (iv) various geophysical phenomena such as aurora, airglow and noctilucent clouds, properties of ionospheric layers and (v) rocket-borne techniques. No direct measurement was available above 200 km. Estimates were uncertain by factors of 100 at 500 km and 10^4 at 1000 km.

The satellites brought a revolution in these studies. Even for uninstrumented satellites the little air that exists in the high atmosphere produces a perturbation of the satellite orbit which can be measured through a network of optical and radio tracking stations. Such a network was quickly set up soon after the first artificial satellite Sputnik I was launched (including the network of twelve Baker-Nunn cameras distributed globally, one being at Nainital). The work of building up atmospheric models from observations of satellite drag was started at several places in the world, notably by the Smithsonian Institution in USA and later by Priester in West Germany and King Hele in England. In India also an effort was initiated at the NPL (Mathur and Mitra, 1960).

Atmospheric drag is only one of several perturbing forces acting on an artificial satellite. Perturbing forces also arise from the irregular shape of the earth, from the pressure of solar radiation, and from the gravitational attraction of celestial bodies. Fortunately their effects in a specific orbital element are different and have little relation to their relative intensities. While atmospheric drag has a noticeable secular decrease of the semi-major axis, the much larger force from the gravitational

anomalies leave the semi-major axis quite undisturbed. Consequently for time intervals larger than one revolution there are only two contending effects: atmospheric drag and solar radiation pressure. For a relativelly close satellite with a moderately eccentric orbit ($0.1 < e < 0.2$), the two are equal when $\rho \sim 10^{-16}$ gm/cm^3. At time of sunspot maximum this occurs at 900 km, but during low solar activity it occurs as low as 400 km. Thus if one wants to determine atmospheric drag with 10 per cent accuracy or better, the effect of solar radiation pressure must be considered whenever the perigee height of the satellite is greater than 400 km.

The derivation of atmospheric density from the analysis of orbital decay is based on the interaction of the satellite with the surronding gas. The basic equation used was:

$$\rho_{\pi} \sqrt{H\rho} = -K \frac{M}{SC_D} \sqrt{\frac{e\dot{P}}{a}}\, f(e, H\rho, \alpha, i, \omega, \varepsilon)$$

where ρ_{π} is the density at the perigee, $\dot{p}$ the observed rate of change of anomalistic period, M is the mass of the satellite, S the satellite area projected on a plane normal to the direction of motion, C_d is the dimensionless aerodynamic drag coefficient having a value of about 2.24 (with maximum possible error of 8 per cent), and is a function defining the orbit of the satellite. The above equation simply states

$$\rho_H \sqrt{H_\rho} = K \dot{P}$$

or, in other words, the rate of change of the anomalistic period is a direct measure of the product $\rho_H \sqrt{H\rho}$ or a function of both density and temperature.

The first upper air model developed at the NPL by Mitra and Mathur (1960) soon after the IGY, used the drag observations of many of the satellites that were launched during the IGY and IGC. These included Sputnik 1 (1957 α_2) and its carrier rocket (1957 α_1). Sputnik II (1957 β_1) Explorer I (1958 α), Vanguard (1958 β_2) and its carrier rocket (1958 β_1), Explorer III (1958), Sputnik III (1958 δ_2) and its carrier rocket (1958 δ_1). The perigee heights of these satellites ranged from about 230 km to about 650 km. The model is given in Table 1.

In this early model, developed at a time when satellite-based atmospheric models were few, thermospheric temperature was high around 2000°K (higher than in the previous indirect models). The total particle density of 1.77×10^9 cm^{-3} at 300 km was about 2.5 times larger than the pre-IGY models given by Hulbert (1955) and S. K. Mitra (1952). A detailed

comparison of this model with that of S.K. Mitra and the COSPAR International Reference Atmosphere (1965), given in Figure 4, shows that the departures begin from a height somewhat below 100 Km, in the region where O_2 is rapidly dissociated and become increasingly larger at higher heights.

It was soon observed that atmospheric density at altitudes above 200 km is highly variable. The densities derived from the drag of Vanguard 1 for a height of about 700 km continuously increased and decreased by a factor of 2 with a monthly cycle, and occasionally, following magnetic storms, increased by a factor of 5 or more. As solar activity started decreasing, the density also decreased. In mid-1963 Vanguard 2, at 600 km and in the dark hemisphere, was encountering an air density 100 times smaller than earlier in 1959, when the perigee was in daylight.

The tremendous variation of high atmospheric densities with solar activity necessitated the development of atmospheric models for different solar activity conditions, and especially for the International Quiet Sun Period (1964-65) when the sun was at its minimum. An international group of scientists was already engaged under COSPAR to provide models appropriate for different solar activity conditions. At the same time Bhatnagar and Mitra (1966) at NPL developed a new atmospheric model for the height range 100-700 km, believed to hold for solar minimum conditions. To construct this model they used the satellite drag observations of 46 satellites, covering different periods of solar activity and over a substantially wide range of perigee heights. Since in the final analysis one must have the distributions of the individual atmospheric constituents, and not merely the atmospheric density the work went further to derive the distributions of O, O_2 and N_2, as in the previous work of Mitra and Mathur, and also of hydrogen and helium, whose existence was by that time well established. The high ionospheric temperature of 2000 K had come down to some 700 K during the IQSY, the total practicle concentration was also about one order of magnitude less. The detailed distributions of the individual constituents derived by Bhatnagar and Mitra are shown in Figure 13. These showed the increasing predominance of lighter atoms at high levels.

The second most important variation in atmospheric density observed was the diurnal one. The maximum was reached about 1400 hrs and the minimum around 0400 hrs, and the variation was found to be important only at heights about 200 km. The average day-to-night ratio of the exospheric temperature was about 1.3. The distributions shown in Figure 13 represent the maximum daytime and minimum night time values given by the Bhatnagar-Mitra model. The differences were large.

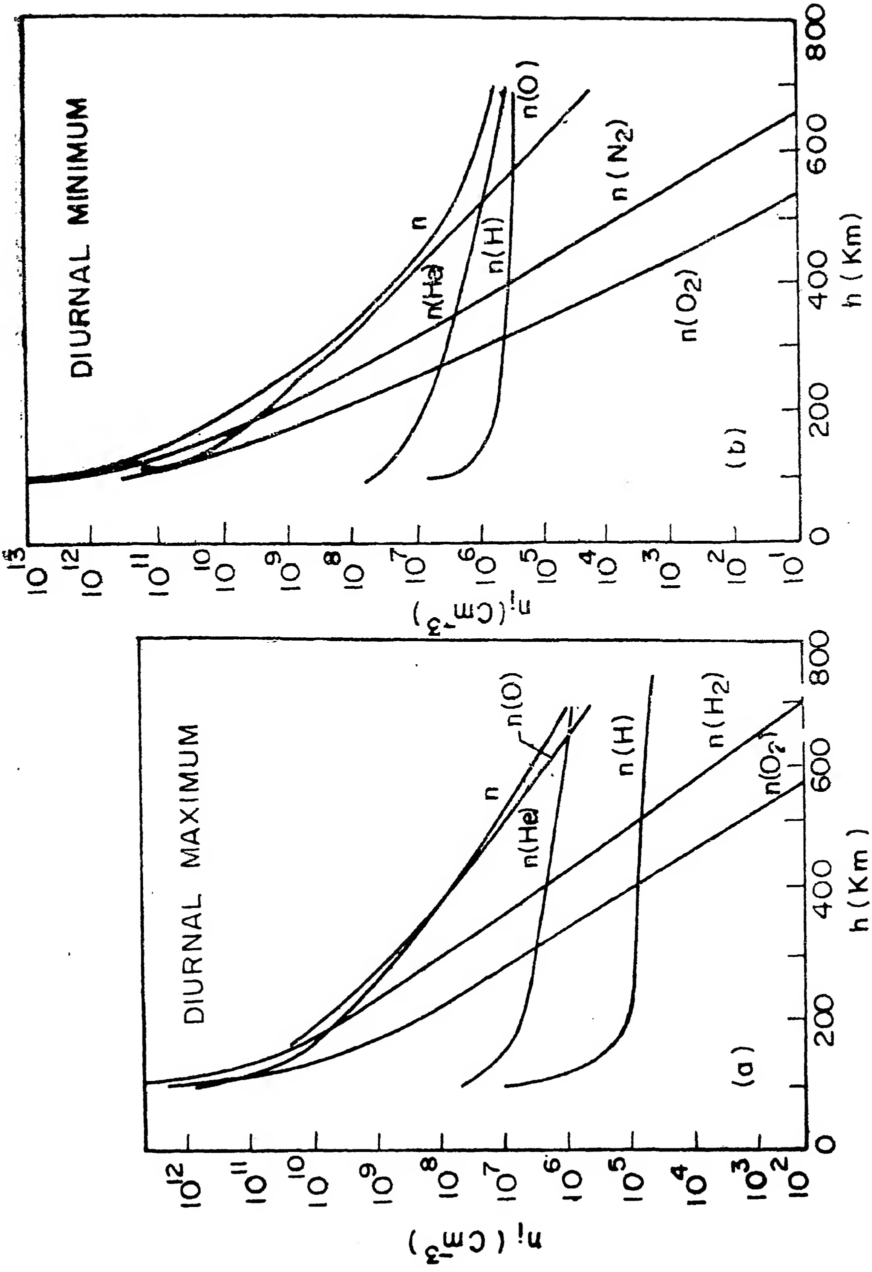


Figure 13. Distribution of the individual constituents derived by Bhatnagar and Mitra (1966) showing increasing preponderence of lighter atoms at higher levels.

It has been a matter of some satisfaction that the Bhatnagar-Mitra model showed better agreement with direct *in-situ* observations (that soon became available) than the International Reference Atmosphere CIRA, 1965 (Table 5), and that the Mitra-Mathur model provided one of the main inputs in the first COSPAR International Reference atmosphere (Table 6).

Table 5 *Exospheric temperatures for low solar activity* ($F_{10.7}$=70 *units*)

	Bhatnagar Mitra	CIRA 1965	Jacchia	Spencer et al	Reber and Nicolet
Daytime maximum (T_{max})	860	1024	850	825	825±75
Nighttime minimum (T_{min})	670	705	650	725	650—700

*Thermospheric probes in rockets, N_2 measurements.
**Mass spectrometers in Explorer 17.

Table 6 *Molecular weight and temperature at 500 Km.*

Condition	Mol. Wt.	Temp. (°k)	Source
Average	16.00	1591	Mathur and Mitra
	17.48	1474	CIRA 1961
	18.32	1580	Nicolet
	16.85	1389	Kallman-Bijl

5.2 The Ionosphere

The classical picture of the pre-IGY ionosphere changed beyond recognition after the IGY. The most pronounced change was in the extent. The pre-IGY picture was that of an ionosphere confined to a narrow shell of 50-600 km, and consisting of three specific layers: D (50-100 km), E (100-150 km) and F (150-600 km). Observations from satellites and space probes, and from whistlers, showed that the outer ionosphere extends to a distance of several earth radii from the earth's surface.

The second major change was in the picture of ion composition. The ionic structure was found to be neither uniform nor stable. There was an unexpected predominance of NO^+ for a major part of the bottomside ionosphere and virtual absence of N_2^+ ions, indicating importance of ion chemistry. In the attempt to understand the observed distribution of ions, a whole new area emerged—"Ion Chemistry".

5.2.1 The Outer Ionosphere

One of the first glimpses of the outer ionosphere that changed the classical ionospheric picture came from Mitra and Shain's use of galactic radio noise as a sounding tool. The measured attenuation in Hornsby at 22.3 MHz indicated an asymmetric F-region with a slowly decreasing ionization profile and an electron density as high as 10^5 cm^{-3} at 1000 km. Observed refraction of radio waves from radio stars whose positions were well known confirmed this result, Shortly afterwards Mitra and Sarada derived the topside ionization distribution (Figure 14) from cosmic radio noise measurements made in Delhi. Ionization profiles were derived for heights above the F-region maximum level by simultaneous use of ionograms and subtracting absorption from the bottomside F2-region. The average profile obtained was given by:

$$N = N_0 \exp\left[-6.6 \times 10^{-3} (h - h_0)\right]$$

and was in agreement with early Russian estimates from radio observations of satellites. It is satisfactory to note that current profiles (deduced from incoherent scatter observations) are also quite close. However, since less than 10% of the absorption comes from above 600 km, the above profile shape could not be extended beyond this height.

The whistlers took us further out in space. Estimates of electron density are possible from observed dispersion of whistlers at different geomagnetic latitudes. With increasing values of the latter the field lines extend to increasingly higher altitudes. Alongwith Allcock (1959) of New Zealand and Helliwell (1960) of Stanford and others, there was some effort by the Indian scientists (Ghosh and Bist, 1961) to determine electron densities in the exosphere. They used two nearby stations for which whistler spectrograms were available (e.g. Stanford and Seattle), assumed the earth to be a magnetic dipole, used the time delays between two consecutive echoes for a given whistler frequency from the spectograms, and then obtained electron densities through the equation:

$$\frac{dD}{dS} = \frac{D_2 - D_1}{S_2 - S_1} = \frac{1}{2c} \frac{f_b}{f_h}$$

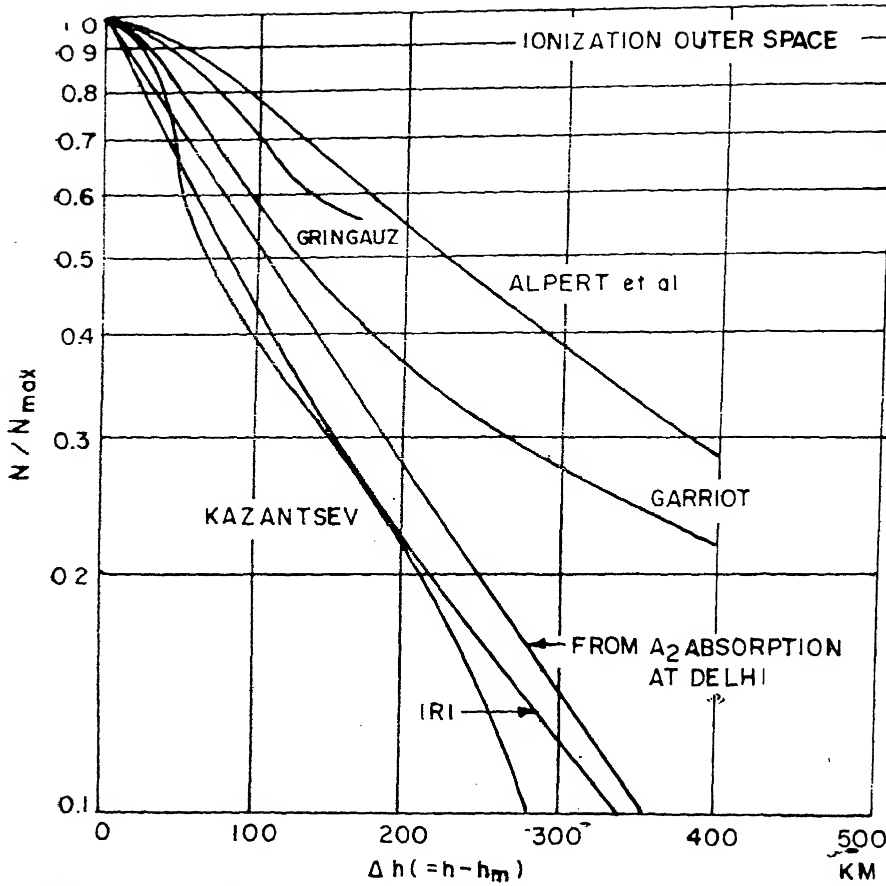


Figure 14. Topside ionization distribution of Sharada and Mitra (1962) derived from cosmic radio noise measurements.

where D_1 and D_2 are dispersion paths for whistler stations A and B, S_1 and S_2 are path lengths for the field lines for A and B; f_H is the gyrofrequency along the field time. They used the spectrograms of stations Stanford (45°N), Boulder 48°N) and Seattle (51°N) and derived electron density values of 1.2×10^4 cm^{-3} at 1125 km, 3.8×10^3 cm^{-3} at 5000 km, 1.1×10^3 at 9000 km and 1.2×10^3 cm^{-3} at 10,000 km, fairly close to current values of exospheric ionization. The riometer-deduced profile of Mitra and Sarada and the whistler deduced profile of Ghosh and Bist are shown in

Figure 15 alongwith a model ionosphere prepared by Jackson (and reported by Townsend, 1960) from a number of direct and indirect measurements during the IGY.

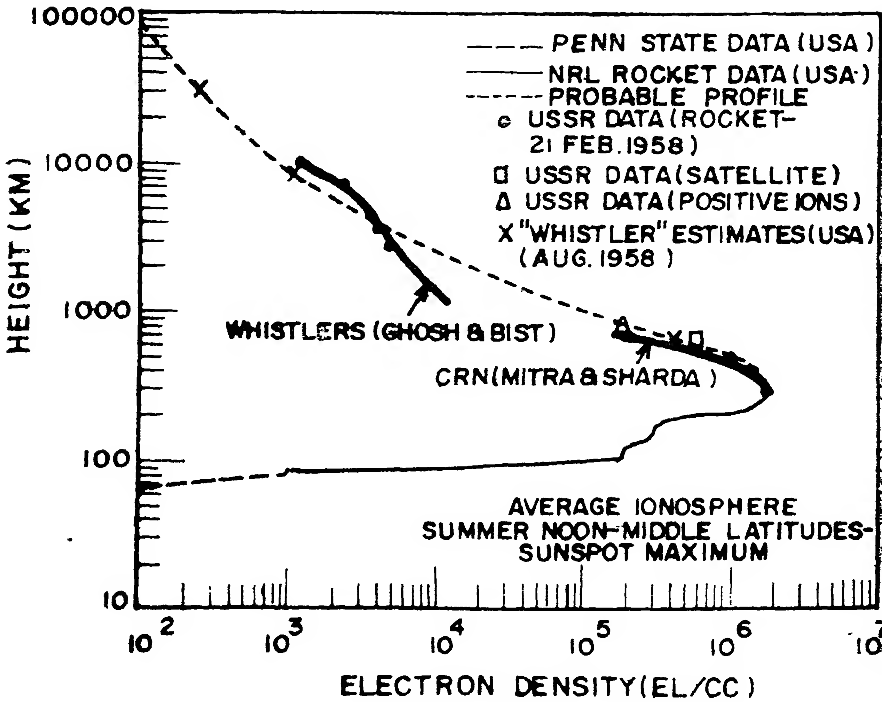


Figure 15. Model ionosphere of Jackson alongwith riometer-deduced profile of Sarada and Mitra and that of whistler deduced profile of Ghosh and Bisht.

5.2.2 Cosmic Radio Noise Technique

The cosmic radio noise method (first introduced by A.P. Mitra and Shain in 1951) proved to be one of the most versatile groundbased methods for geophysical studies. Apart from the first glimpse it offered on the outer ionosphere, one of its most remarkable achievements was the detection of PCA events caused by low energy cosmic rays impinging on the atmosphere immediately after major solar flares. Since such cosmic rays are readily attenuated in the atmosphere, they are not often observed on the

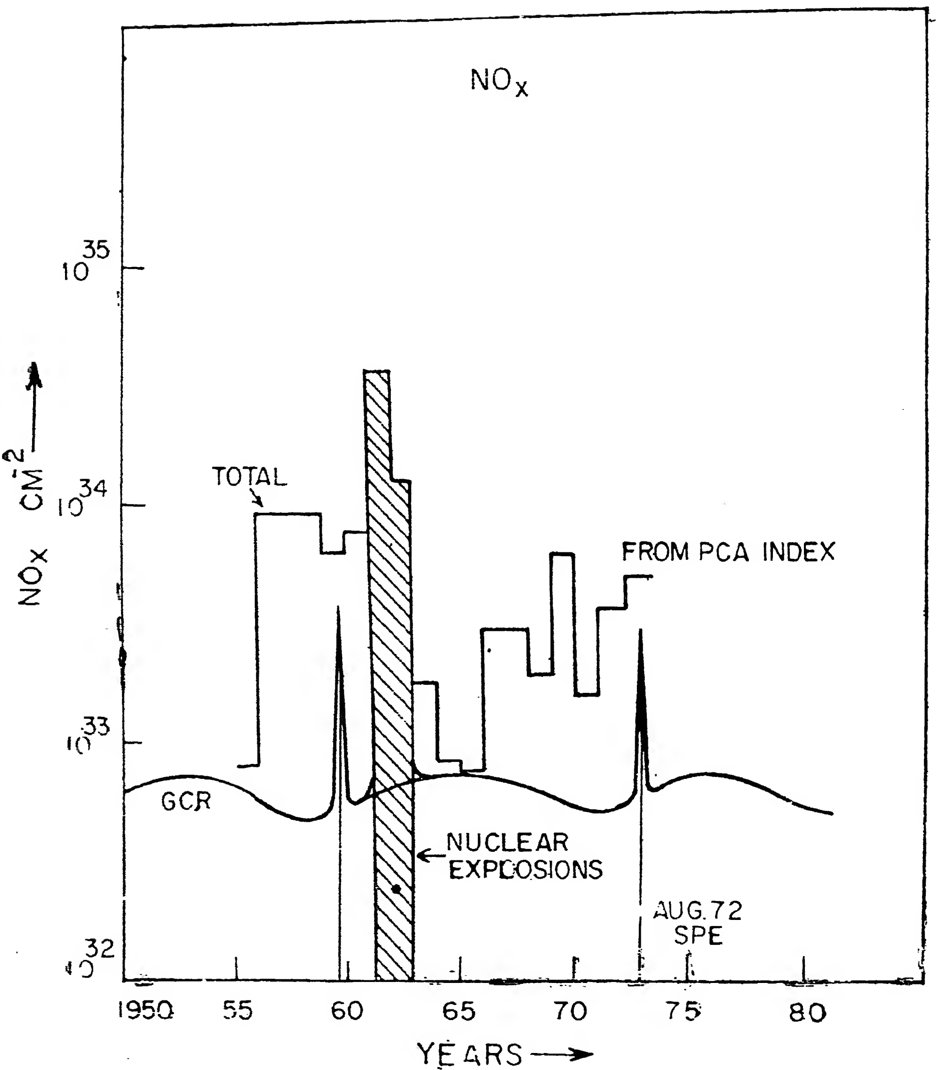


Figure 16. NO_x production from proton events vis-a-vis manmade activities (e.g. nuclear explosions) (after Mitra 1982).

ground. A frequency around 30 MHz was generally used. A very large number of solar proton events were observed during the IGY and the IGC the most significant (PCA $\geqslant$ 15db) occurred on 7th July 1958, 26th August 1958, 10 May 1959 and during the specially declared period July 59 (10, 14 and 16 July). The events on 23 February 56, 10 May 59, 10 July 59, 14 July 59 and 16 July 59 were particularly severe, peak flux for particles $\geqslant$ 30 Mev were estimated to be 6200, 7000, 4000, 11,000 and 17,000 particles/cm^2 sec steradian. Recent estimates of the ion pair production globally for these events are: 2×10^{32}, 4.8×10^{32}, 1.7×10^{32} and 6.14×10^{32}. Such large events, we now know, have several impacts: firstly, with such large ionization rates, they swamp the ion production due to galactic cosmic rays (GCRs) normally the only source of stratospheric ionization; secondly, these also became a major source of injection of NO_x into the stratosphere and, for large events, can cause a substantial depletion of ozone in the stratosphere; thirdly, order of magnitude decrease in vertical electric field can (and has indeed been seen to) occur in the stratosphere. A catalogue of individual proton events during the IGY in the context of events occuring during the last three decades, as well as the history of NO_x production from proton events vis-a-vis manmade activities (e g. nuclear explosions) are shown in Figure 16 (Mitra, 1982). The latter was summed over one year period to take care of the long residence time. The main point here is that solar particle events occur more frequently during sunspot maximum year (as in the IGY) than the sunspot minimum years, the maximum occurrence being during the decreasing solar activity just after the maximum. Consequently there is a solar cycle modulation of this input and one would expect the injection to have been the largest during 1957-58 when the solar activity was the highest for the last 200 years.

Apart from the information of topside ionization and of PCAs, the technique (i) provided the largest series of continuous measurements of total ionospheric absorption of temperate latitude stations (principally Delhi and Ahmedabad), (ii) provided a new method of detection of solar flares (now a part of regular monitoring programmes in many observatories) and (iii) allowed detection and study of atmospheric nuclear explosions (later in the early sixties when a series of large atmospheric nuclear explosions were undertaken by the USA and the USSR).

Although the technique was usually recommended only for high latitudes, Indian observations showed that it is possible to get consistent results, *even for normal absorption*, at lower latitudes (especially in the zone of high f_o F2, as in the Indian stations (Figure 17) with proper choice of frequency, narrow beam antenna and a long series of observations (as in the Indian stations, Delhi and Ahmedabad). In the detection of atmospheric nuclear explosions, the method was found to have the additional

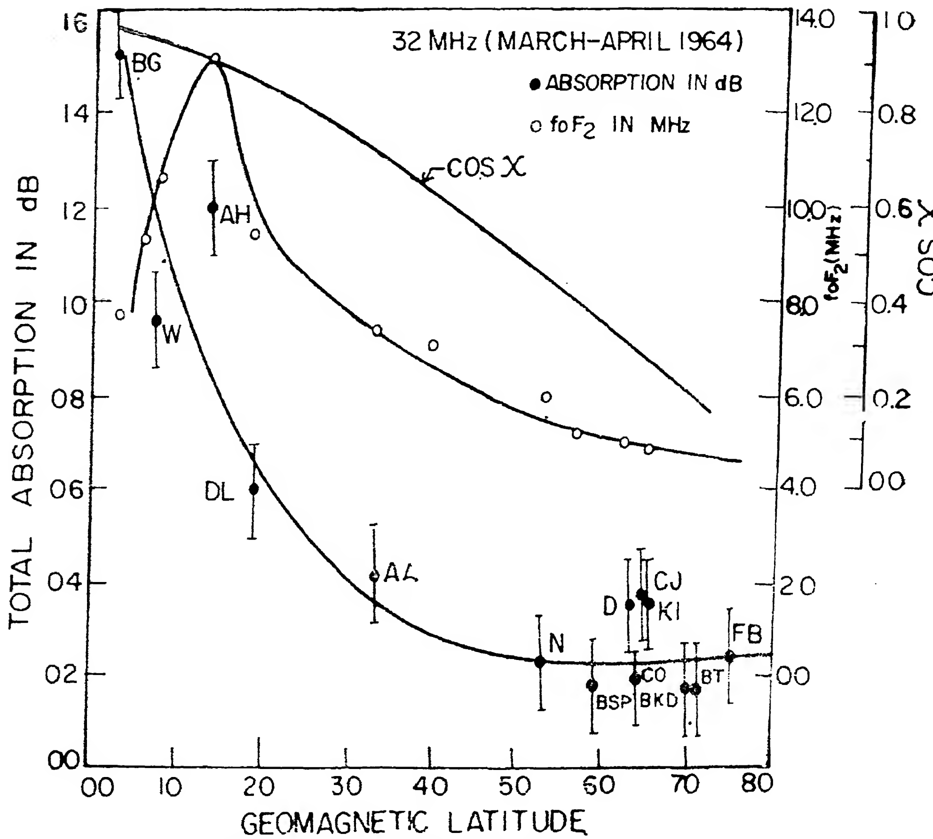


Figure 7. Riometer absorption as a function of geomagnetic latitude showing large absorption in equatorial latitudes. BG (Bangalore), AH (Ahmedabad), W (Wattair), DL (Delhi), AA (Askhabad), KI (Kiruna), CO (College), FB (Fairbanks), N (Neustralitz), D (Dixon Islands)

advantage of separating the D-and F-region effects as can be seen in Figure 18, where the results of detection of several atmospheric nuclear explosions by the NPL cosmic radio noise equipments are outlined (Saha and Mahajan, 1964).

5.2.3 Polar and Equatorial Phenomena

The polar and equatorial phenomena naturally received great amount of attention during the IGY, and, as we have seen, in both regions many new stations were set up. There was, of course, no direct Indian contribution to the study of polar ionospheric phenomena, excepting in interrelating phenomena that are coupled with equatorial regions such as ionospheric storms.

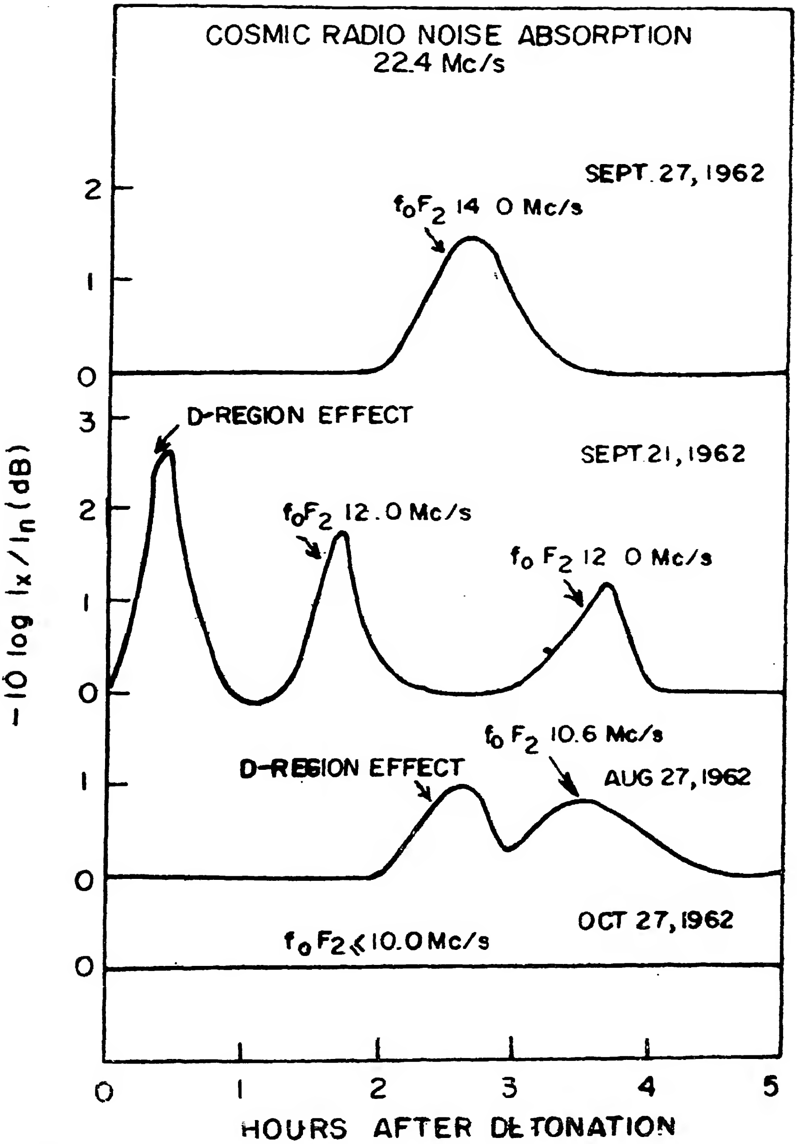


Figure 8. Comparison of a few cases of cosmic radio noise absorption effects showing separation of D and E region effects due to nuclear explosions (Saha & Mahajan, 1964).

However, in the area of equatorial phenomena, Indian contributions were the most significant. Of the three principal equatorial chains (see also *sec* 4.4) the Indian chain of stations is still largely operative whereas in the American and African chains many stations have now closed down. Furthermore, some of the Indian equatorial stations had, and continue to have, a wide spectrum of activities: atmospheric physics, ionosphere, solar physics, cosmic rays, geomagnetism; and new techniques have in recent years been added. Even in the field of ionosphere alone, one had simultaneous measurements of ionization profiles (through ionosondes), of absorption (often through more than one technique), of ionospheric drifts, of atmospherics. and with the ready availability of magnetic and solar measurements at Kodaikanal, it was possible to examine the disturbed ionosphere at low latitudes in several aspects.

The principal targets were: (a) an examination of the equatorial anomaly belt and its changes under both normal and disturbed conditions. and (b) the response of the equatorial ionosphere to geomagnetic disturbances (quite different for different latitudes). Both could be examined in terms of ionization, absorption and drifts.

The geomagnetic anomaly belt was already known to be confined generally within $\pm$ 30° magnetic dip, but its variabilities and differences in the three longitudes zones were to be charted. One had noticed also distinct differences in the geographical-cum-geomagnetic configurations and the fact the gradient lines are not the same in the three zones-there is comparative rarity in the south American region (Figure 19). The anomaly first pointed out by Appleton can be seen in Figure 20 in which values of noontime F2 layer critical frequency are plotted for different stations against magnetic dip, magnetic latitude and geographic latitude. The values line up if the magnetic coordinates are used, showing geomagnetic control of the ionization, but more surprisingly the peaks occur not at the equator but around+30° and—30°. The first explanation of this curious phenomena came from S.K. Mitra soon after its discovery: he suggested electrons and ions move along the magnetic lines of force (at these heights the collision frequency is small), moving downwards to lower attitudes at the higher latitudes. Later Martyn supplemented this by invoking increase in Hall conductivity over the dip equator and upward movement of plasma by electrodynamical drift, which is then followed by diffusion down the magnetic lines of force. During the IGY a considerable amount of work was done on this anomaly (in India and elsewhere), its variation with diurnal time and solar activity, and its inhibition during magnetic storms. Rastogi (1963) assumed that the horizontal transport of ionization is away from the equator in the forenoon

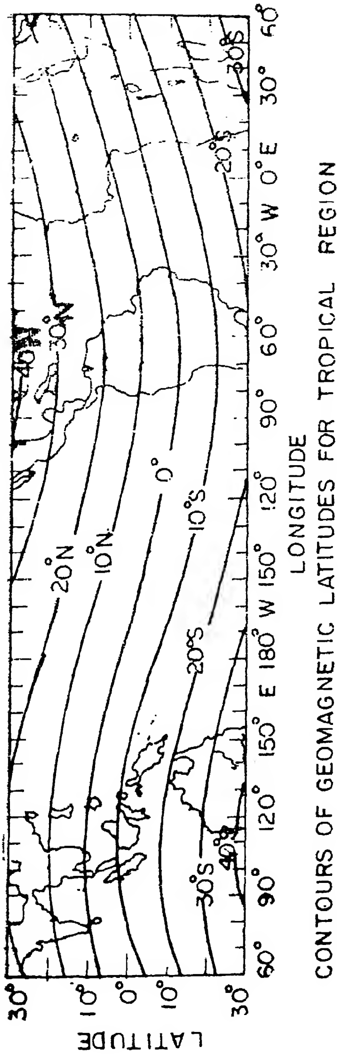


Figure 19. Contours of geomagnetic latitudes for tropical region.

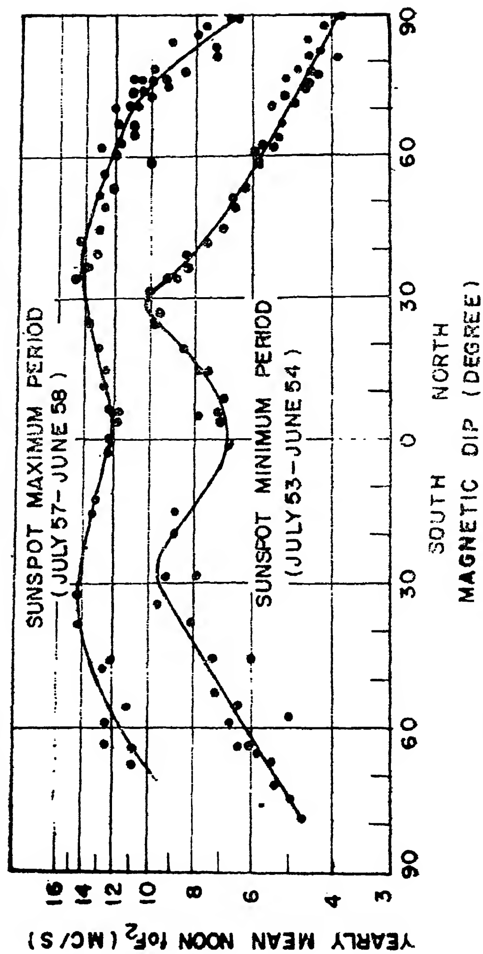


Figure 20. Geomagnetic anomaly-magnetic dip as mean noon foF_2 values.

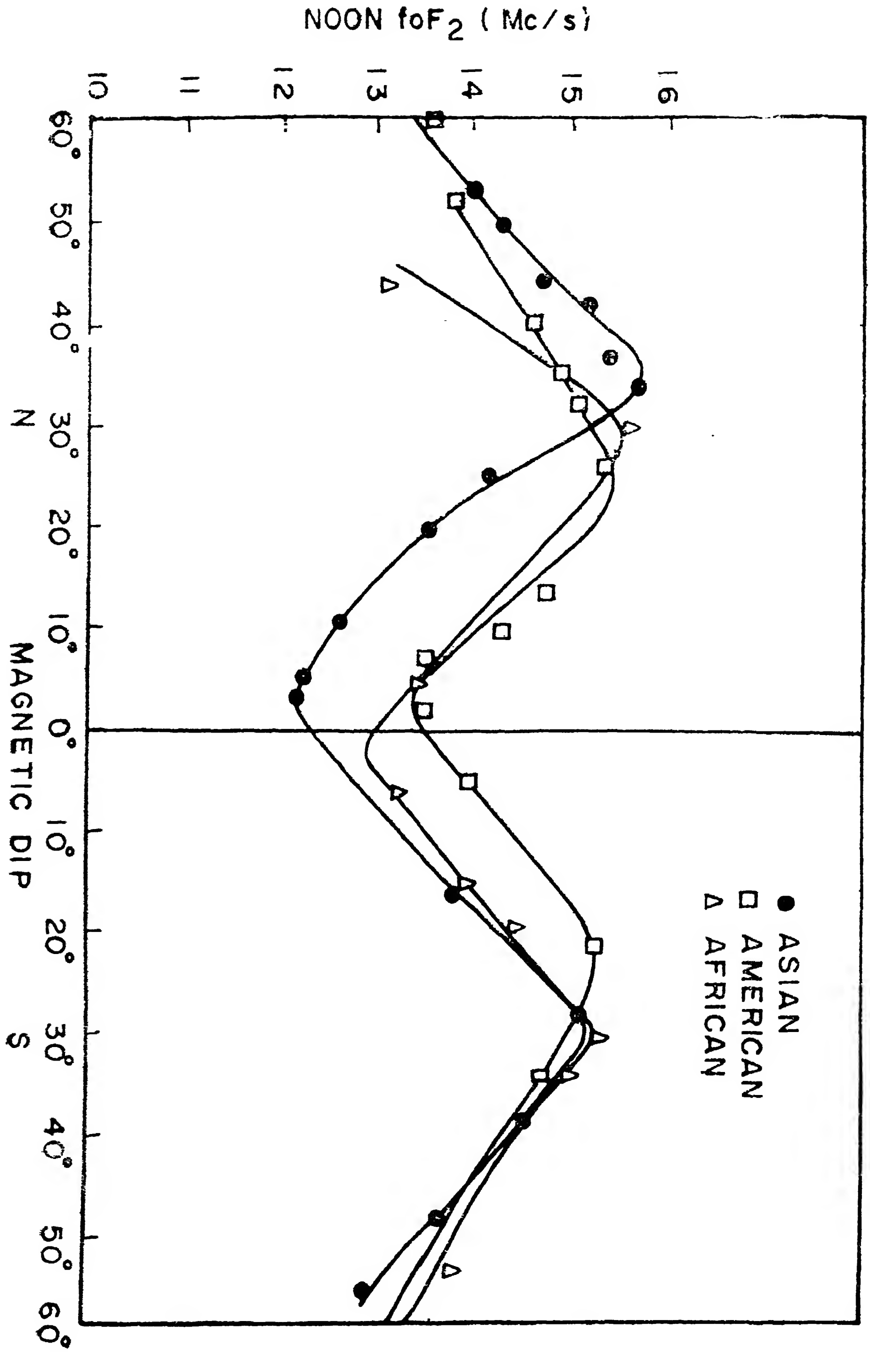


Figure 21. The variation of noon foF_2 with dip in the Asian, African and American zones (after Rao, B.C.N., 1963).

and towards the equator in the afternoon and furthermore the direction of motion of ionization is parallel to the gradient of magnetic dip. Since the isodip lines are highly curved in the southern hemisphere, but almost parallel to the geographic latitude in the Asian and African zones, the nature of transport away from the equator is substantially different between the American and Asian zones. The difference, quantitatively examined by B.C.N. Rao (1963), is given in Figure. 21.

There was also evidence of solar control on the nature and magnitude of the anomaly. With solar activity the peak got broader and the valley shallower i.e. the location of the peaks oscillated with solar activity. Thus, Kotadia and Ramanathan (1962) noted that while in 1954 the peak was between Ahmedabad and Bombay, in 1957 (high activity) it shifted to a position slightly north of Ahmedabad. Other significant points were:

(1) The noontime trough is more pronounced during sunspot maximum and lasts longer, being absent only around 0900 hrs. At sunspot maximum the evening crest of f_o F2 vanished.

(2) Stations within the anomalous equatorial belt exhibited a striking postsunset increase in h′F. This anomaly was again confined to $\pm$ 30° dip.

(3) The three equatorial chains did not behave identically; the width of the belt was larger for the Asian and African chains than for the American chain; for the former the width was around $\pm$ 35-30° in magnetic dip, for the latter around $\pm$ 25°. The amplitude of the postsunset increase in h′F was larger in the Asian zone than in the American zones, the corresponding values of h′F being about 240 and 200 km respectively.

(4) True height profiles for equatorial stations showed a sharp increase in N_e at sunrise, the lower levels developing maximum earlier than the higher levels.

(5) The equatorial sporadic E (E_{sq}) in the American zone was confined within a very narrow region (about $\pm$ 5°) about the geomagnetic equator—narrower than previously supposed, but consistent with the electrojet width estimated by Forbush.

Apart from the determination of ionization profiles by ionosondes, the equatorial ionosphere was studied by a multitude of techniques. These included (for India) measurements of absorption and drift and (in the USA) incoherent scatter experiments and VHF equatorial forward scatter.

Indian absorption measurements included principally A1 (transmitter) and A2 (cosmic radio noise) techniques.

Two central parameters for geophysical studies are the solar zenith angle dependence of absorption found to be normally of the type:

$$\log \rho \propto \cos^n \chi (n \sim {}^3/_4)$$

and the frequency dependence generally of the form:

$$\log \rho \propto (f \pm f_L)^{-m} \; (m \sim 2)$$

with average values as indicated above for midlatitude stations.

The low values of the cos χ exponent obtained with most absorption results in midlatitudes, coupled with the fact that an inverse frequency square law was still obtained, were interpreted (Mitra and Jain 1963) to mean that a variable recombination coefficient is involved. In the mesosphere α must vary with height. The actual α-profile used by Mitra and Jain consists of two parts, one essentially independent of height (determined by the dissociative recombination coefficient) and the other rapidly varying with it (and connected with the production and loss of negative ions).

A detailed comparison of the variations in absorption with those in X-rays at the different wavelength bands for which satellite measurements soon became available (0-3 A, 0-8 A, 8-20 A, 44-60 A) provided information on the relative importances of the various ionization sources. The much smaller variations in HF absorption (a factor of 2-3) compared to orders of magnitude changes in X-ray suggested that the predominant source at the peak absorption level is not X-ray ionization but photoionization of NO or O_2 ($^1\Delta_g$). On the other hand, Sen Gupta (1968) observed excellent agreement between 30 MHz riometer absorption (recorded in Bedford, Mass) and the parameter F(2-12 A) $(\cos \chi)^{0.65}$, F(2-12A) being 2-12A flux measured by the University of Iowa on Explorer 33. His empirical relationship relating this absorption with X-ray flux in the different wavelengths was:

$$L(db) = 1/f^2 \, [135 + (100\text{-}310\sqrt{F(20\text{-}100A)} + 4700\sqrt{F(1\text{-}10A)} \; (\cos\chi)^{0.65}]$$

where L is the cosmic radio noise absorption in db at frequencies > 20 MHz ($f \gg f_h$). According to him, on a day of high solar activity the X-ray ionization caused about 40 per cent of the total absorption and about 80 per cent of the D-region absorption. The second term on the right is the contribution due to solar EUV radiation. On this interpretation, it was possible to obtain probable upper limit for nitric oxide concentration.

The 3-station fading technique of measurement of ionospheric drifts, used very extensively in India, as well as many other countries was originally developed by S.N. Mitra under the guidance of Ratcliffe in Cambridge. The IGY measurements of ionospheric drifts were mostly at Delhi, Ahmedabad and Waltair, none within the electrojet area, but the

last two within the equatorial zone. Analysis of some ionospheric drift data of thirteen stations by Briggs showed that, in accordance with the then existing theory of electrodynamical drift, the E-W component of mean drift velocity (at midnight) reverses its direction in the region of 30° magnetic latitude. At higher latitudes the drift is towards the west and at lower latitudes, towards the East. During midday the direction appeared to be opposite to those at midnight. The N-S component, which should vanish at the equator, remained appreciable at Singapore and Waltair.

5.2.4 Response of the Equatorial Ionosphere to Geomagnetic Disturbances

A frequently used index of this response was the quantity D (foF2)/ Q (foF2), D and Q referring to disturbed and quiet day values. This quantity was found to be less than 1 at high latitudes and greater than 1 over a belt centered on the magnetic equator. The width of this belt, it was already known, is roughly equal to that of the Appleton belt. The Indian observations showed that the transition region occurred sometimes at Calcutta, sometimes at Bombay, but rarely at Ahmedabad or Madras; and it was also confirmed that the transition for geomagnetic disturbance effect and for the equatorial anomaly occurred at about the same location. Another interesting result was the disappearance of the "biteout" during a disturbance. The "biteout" is the abnormal decrease in noontime ionization in the F2 layer, with the consequent appearance of two maxima, and is only observed within the anomaly belt.

There were other effects. The equatorial trough was flattened out. Although the midday biteout was removed, the diurnal variation was still not of Chapman type. The normal postsunset rise foF2 in Ahmedabad was suppressed.

Irregularties also got suppressed. Spread echoes were rare during magnetic activity; there was also a decrease in cosmic radio noise absorption.

5.2.5 The Physics ond Chemistry of the Ionosphere

The IGY saw the emergence of a new area: ionospheric chemistry. The starting point was some very surprising results about ion composition in the ionosphere, as measurements began to become available from RF mass spectrometers flown in rockets and satellites. The unexpected dominance of NO^+ ions over much of the ionosphere where the initially produced ions are O_2^+, N_2^+ and O^+ showed the critical role played by ion chemistry. This prompted laboratory measurements of relevant reaction rates in a number of institutions and ion chemical modelling starting from

reference neutral models. In the latter area two Indian groups were particularly active: that at NPL under A.P. Mitra and at Allahabad University under Ghosh.

The second aspect related to studies on the origin of ionospheric layers—such studies became increasingly sophisticated in quantitative terms as measurements became available on solar flux in the ultraviolet and X-ray regions and their variations with solar activity. In this also, several Indian groups participated, especially the group at NPL.

The third aspect was the study of the loss processes in the ionosphere and the "effective" recombination coefficient.

Ion Chemistry: Ion composition measurements with rockets such as those by Johnson and his colleagues in the USA covered heights up to 250 km. Above these heights satellite-borne mass spectrometers were used: the Russian measurements with Sputnik III (1958 δ_2) covered altitudes from 220 to 980 km in the latitude range 27° to 65°N during daytime. From both the USSR and US observations the following conclusions were made:

(i) The predominant positive ions were: O^+, NO^+, O_2^+

(ii) In the E-region (100-150 km), NO^+ was the predominant positive ion (although neutral nitric oxide is only a trace constituent) with an apparent diurnal-effect, $[NO^+]/[O_2^+]$ being larger during the day.

(iii) Above 200 km the predominant ion was O^+; above 250 km, all other ions became minor constituents.

(iv) As one went up from 100 to 200 km, the order of relative abundance of positive ions changed from (O_2^+, NO^+) at 100 km to (NO^+, O_2^+, O^+) at 150 km and finally to (O^+, NO^+, O_2^+) at 200 km. O_2^+ and O^+ ions were roughly equal at heights 165-190 km. The pioneering set of observations on ion composition obtained by Johnson and his colleagues at NRL (USA), which became the starting point of ion chemistry are shown in Figure 22.

The surprising dominance of NO^+ ions and the virtual absence of N_2^+ ions were attributed to the case with which the initially produced ions O_2^+, N_2^+, O^+ get converted to NO^+ through processes such as:

$$O^+ + N_2 \rightarrow NO^+ + N$$
$$N_2^+ + O \rightarrow NO^+ + N$$
$$N_2^+ + O_2 \rightarrow O_2^+ + N_2$$
$$O_2^+ + NO \rightarrow O_2 + NO^+$$

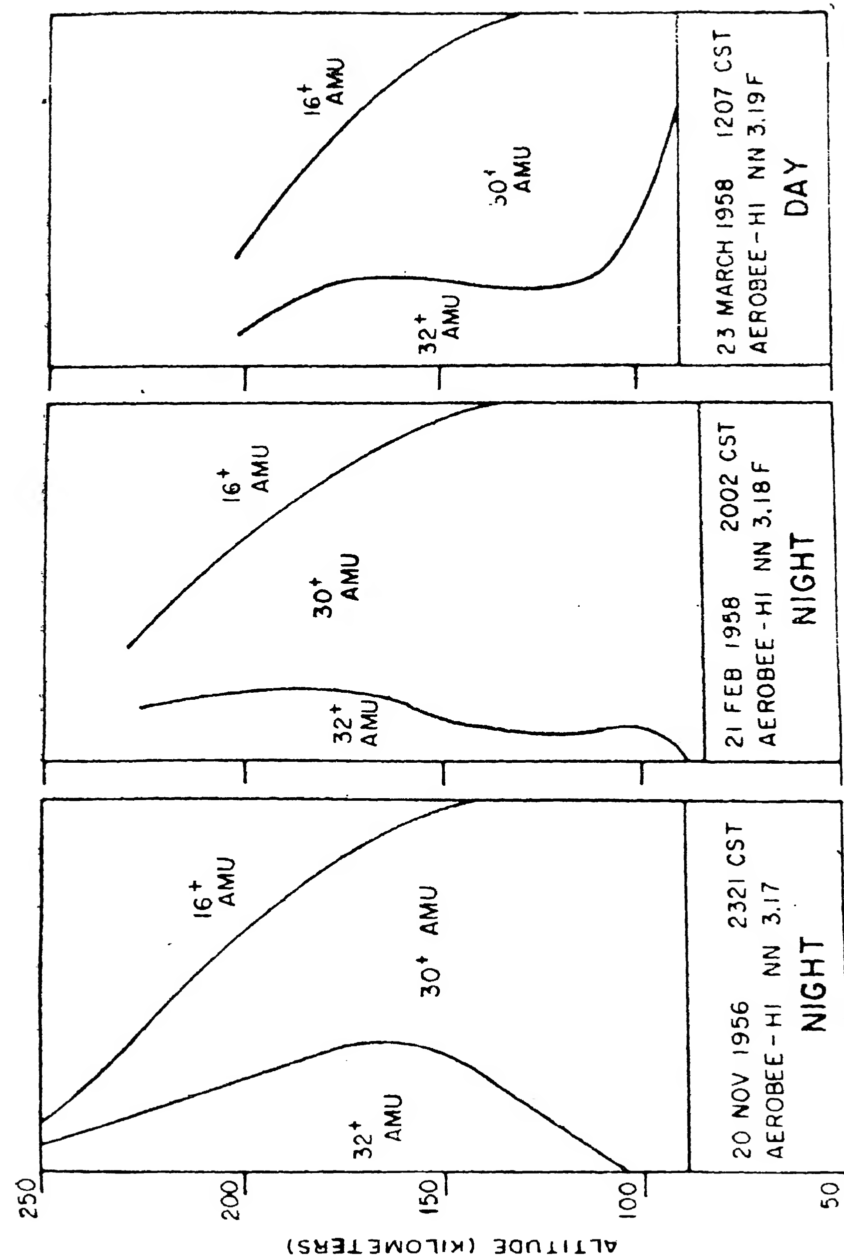


Figure 22. Rocket measurements of Ion composition—Distribution of the major positive ions above Fort Churchill, Canada. (after Johnson, 1956).

The resulting NO^+ ions are destroyed through dissociative recombination:

$$NO^+ + e \xrightarrow{\alpha_D} N + O$$

The ratio $[NO^+] / [O^+]$ was then expected to follow the equation:

$$\frac{[NO^+]}{[O^+]} = \frac{K_1[N_2]}{\alpha_D N_e}$$

The value then available for K_1 was that of Langstroth and Hasted, being 4.7×10^{-12} cm^3/s; value of α_D was not known, but was expected to be of the order $10^{-8 \pm 1}$cm^3/s, so that one expected:

$$\frac{[NO^+]}{[O^+]} = 5 \times 10^{-4 \pm 1} \frac{[N_2]}{N_e}.$$

The Indian workers (Mitra, 1962) examined the observed $[NO^+] / [O^+]$ with varying values of $\frac{K_1}{\alpha_D}$ (figure 23) and found that a close corres-

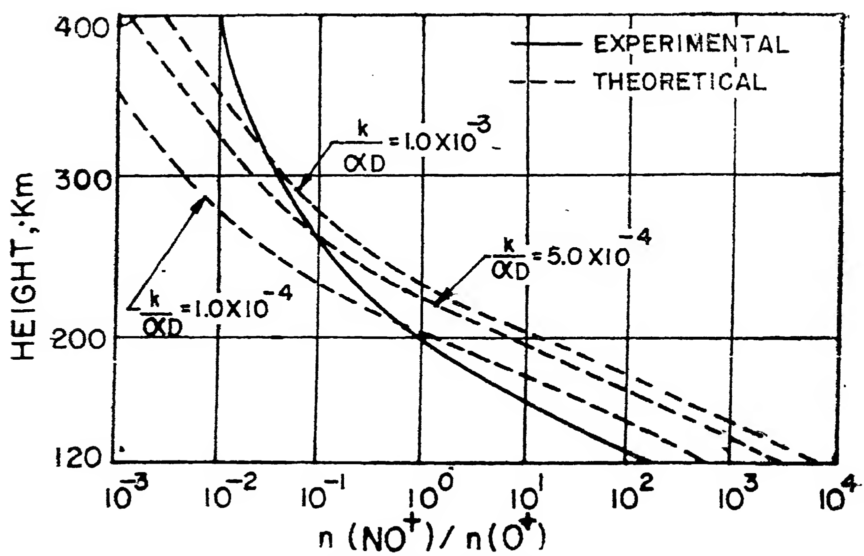


Figure 23. Comparison of the experimentally deduced values of the ratio of $n(No^+)$ $n(O^+)$ (after Mitra, 1962).

pondence exists for $\frac{K_1}{\alpha_D} = 1 \times 10^{-4}$, indicating a value of 5×10^{-8} cm^3/s for α_D (NO^+). With the current value of $K_1 = 1 \times 10^{-12}$ cm^3-s^{-1}, α_D comes

out to be 1×10^{-8} cm^3 s^{-1}. This should be compared with the current laboratory value of about 5×10^{-8} cm^3 s^{-1} corresponding to F region temperatures with the coefficient $4.4 \times 10^{-7} \left(\frac{300}{T_e}\right)^{1.2}$.

5.2.6 *Origin of Ionospheric Layers*

There was much work on the origin of the different ionospheric layers. Outside the polar regions where the effect of solar protons is negligible during quiet conditions the major ionizing source is the UV and X-rays from the sun through process of the type:

$$XY + h\nu \rightarrow XY^{+} + e$$

For such a process the rate of electron production, q, is given by

$$q_h = \eta\, A\,(\mathbf{XY}_h, \lambda)\; n_h\,(XY)\; Q_h$$

where η is the ionization efficiency, A (XY, λ) is the absorption cross-section of the process, n_h(XY) is the particle density of the ionized constituent and $Q_h(\lambda)$ is the photon flux at any height h for the wavelength λ_h. Theories regarding the origin of the ionospheric layers required that precise information should be available on : (i) the photon flux Q(λ) at the top of the atmospheere (ii) the particle density, and (iii) the coefficients η and A. The IGY saw great improvement in our knowledge of some of these quantities, especially of Q and n. Much of these came from information gathered by instruments flown in rockets and setellites. As a result, the origin of ionospheric layers, one of the oldest problems of ionospheric physics, could be discussed with some amount of confidence. The suitability or otherwise of particular process was judged mainly from the following criteria:

(i) Criterion of location

$$A_i n^{+}_{im} \sum A_k n_{km} = \frac{\cos \chi\, (1+\beta_i)}{H_{im}}$$

(ii) Criterion of ionization:

$$N_e = \sqrt{AnQ/\alpha}$$

where suffixes i and k refer to ionizing and absorbing particles respectively. An application of both the criteria and comparison with observed ionospheric characteristics indicated that the following processes are important.

Region D

(i) $NO + h\nu \xrightarrow{\lambda < 1216\text{Å}} NO^{+} + e$ (main source)

(ii) Production of ionization by cosmic rays between 50 and 60 km.

(iii) $M + h\nu \xrightarrow{\lambda < 10\text{Å}} M^{+} + e$ (during solar flares)

Region E

(i) $M + h\nu \xrightarrow{\lambda\lambda 20-100\text{Å}} M^{+} + e$

(ii) $O_2 + h\nu \xrightarrow{\lambda 800-1027\text{Å}} O_2^{+} + e$

The two processes were believed to be competitive, although the ionization of O_2 was considered to be the more important one.

Region F

It was believed that regions F_1 and F_2 have a common origin, two layers being formed due to bifurcation occuring through the height variation of the recombination coefficient α; furthermore ionization occurs not in a single line but over a wide wavelenghth range in the ultraviolet. The wavelength range used was 170-900 Å, including that of the strong resonance line of HeII at 303.8Å

$$O + h\nu \xrightarrow{\lambda\lambda\ 170\text{-}900} O^{+} + e$$

A summary of the relevant data used by the Indian scientists is given in Table 7. Flux values currently available are also shown for comparison within brackets

Table 7 *Basic Photoionization Parameters for Ionospheric Layers*

Region	Process	Spectral Intensities at Normal Incidence (ergs cm^{-2} s^{-1})	Remarks
1	2	3	4
D	L_α (NO)	3	Intensity variable with sunspot activity
	Cosmic rays (50-60 km)	—	Production rate given by $q(\psi) = 10^{-7}$ [M] for $\psi = 50°$
	X-rays (2-8 Å)	10^{-2}	Av. strong flare

1	2	3	4
E	X-rays (20-100 A)	2	—
	800-1027 (O_2)	0 5	—
F	796-911 (O, O_2)	0.3	—
	400-796 (O, O_2, N_2)	0.6	—
	170-400 (Including HeI 304	1.0	All contribute to F production
	and HeII 508)	0.3	—

This picture, we now know, is far too simplistic. In the D-region, for example, there is competing ionization from X-rays above 8A, as well as ionization of O_2 ($'\Delta_g$) molecules by solar radiation of wavelengths less than 1118 Å: for E and F region there are important contributions from Lyman-β (1026Å), C III (977 Å) and for the lower ionosphere at higher latitudes and during solar flare events there is also additionally ionization by precipitating high energy particles.

5.2.7 Ionospheric recombination coefficient

A critical parameter for describing temporal changes in ionospheric ionization is the effective recombination coefficient α, usually a result of several complex processes. It was already known that the nature of these processes is quite different at different levels of the ionosphere and the value of α changes from 10^{-5} cm^{3}s^{-1} at 60 km to about 10^{-11} cm^3 s^{-1} at 300 km (a decrease by six orders of magnitude). A comprehensive α-model covering the heights 60-500 km was first provided by Mitra (1959) (shown in Figure 24) ; this was widely used with occasional modifications. The modifications were principally for the heights below 90 km, where values were found to be larger because of the presence of watercluster ions, which are now known to have large dissociative recombination coefficients ($\sim 10^{-6}$ cm^3/s.).

Since no single process could be assumed to cover such a wide range of altitudes, Mitra considered several processes: processes involving negative ions (and expressed by the parameter $\lambda\alpha_i$, λ being the ratio of concentrations of negative ions and electrons and α_i : the coefficient of recombination between positive and negative ions), dissociative recombination processes (expressed by α_D and applicable only to molecular ions) and atom-ion interchange proceeses (such as those that convert the atomic ions

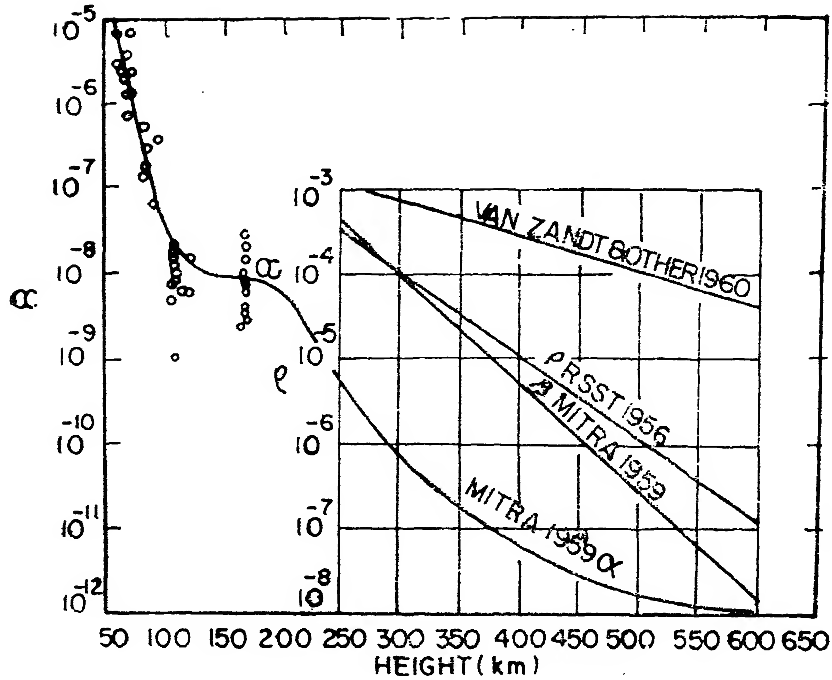
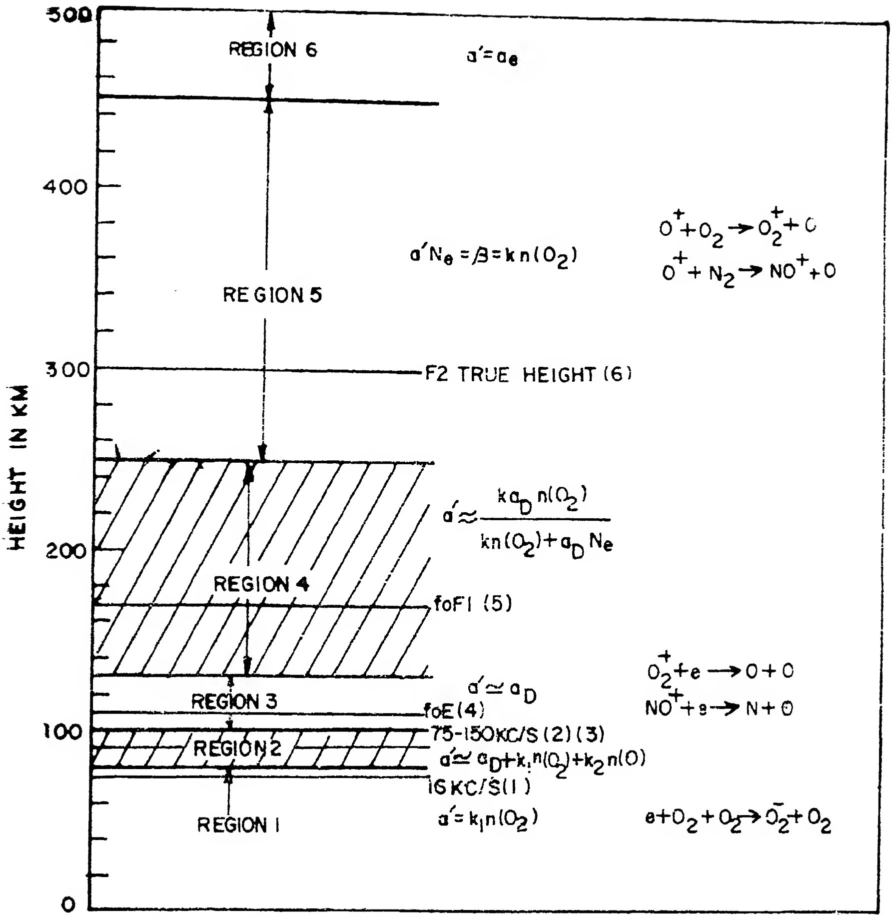


Figure 24. An empirical distribution of the effective recombination coefficient near noon for heights 50-600 km given by A.P. Mitra (1959).

to molecular ions), which then go through dissociative recombination. As the first step he selected the most dominant process or processes for different height regions and generated or used experimental data that would relate to specific coefficients for these height regions. His classification of the ionospheric regions in terms of the dissipative processes is shown in Figure 25. He pointed out that as we go from 60 km to 600 km, we go from regions dominated by negative ions ($\lambda\alpha_i$ term) to a combination of dissociative recombination and negative ion processes ($\alpha_D + \lambda\alpha_i$), to regions controlled entirely by dissociative recombination (90-150 km. α_D terms), then to a transition region where atomic and molecular ions are nearly equal, and then finally to a region of atomic ions where atom-ion interchange converts O^+ ions to O_2^+ and NO^+ ions followed by dissociative recombination. The single expression that will cover the entire region from 60 to 600 km, was given as :

$$\underbrace{\alpha = \alpha_D + \lambda\alpha_i}_{\text{Lower Ionosphere}} + \underbrace{\frac{k\alpha_D\,[YZ]}{K\,[YZ] + \alpha_D N_e}}_{\text{F1 and F2 regions}}$$



CLASSIFICATION OF REGIONS IN THE IONOSPHERE ON THE BASIS OF DISSIPATIVE PROCESSES (AFTER MITRA , 1959)

Figure 25. Classification of regions in the ionosphere on the basis of dissipative processes (after A.P. Mitra, 1959).

or, on the assumption that negative ions are formed by attachment to atomic and molecular oxygen, by:

$$\alpha=\alpha_D+k_1\,[O_2]+k_2\,[O]+\frac{k\alpha_D\,[YZ]}{k\,[YZ]+\alpha_D\,N_e}$$

He then stated that α over the entire ionosphere is completely specified if experimental data are used to give estimates for k_1, k_2, k, α_D. This he did

by using Cambridge VLF observations (yielding k_1), Penn State observations on 75 and 150 KHz (yielding k_2), f_oE observations from Washington (yielding α_D) and true height profiles (yielding k).

With these he derived the following expression.

$$\alpha'=5\times10^{21}\,[O_2]+3\times10^{-20}\,[O]+\frac{2\times10^{-19}\,[O_2]}{2\times10^{-11}\,[O_2]+10^{-8}\,Ne}+1\times10^{-12}\ \mathrm{cm^3/s}$$

In the F region this is reduced to an attachment type coefficient given by:

$$\beta=2\times10^{-11}\,[O_2]\ \mathrm{cm^3 s^{-1}}$$

In Table 8 α and β values derived by Mitra during the IGY are shown along with current values. The appropriateness of these early values are to be noted.

Table 8

		A.P. Mitra (1959)	
Height km	Ne	α $\mathrm{cm^3s^{-1}}$	β $\mathrm{s^{-1}}$
60			
80			
100			
120	1.5×10^5		
150	2.5×10^5	9.2×10^{-9}	
200	2.5×10^5	5.6×10^{-9}	
250	7.5×10^5	5.6×10^{-10}	4.4×10^{-4}
300	1.0×10^6	7.7×10^{-11}	7.6×10^{-5}
350	9.0×10^5	2.1×10^{-11}	1.8×10^{-6}
400	8.0×10^5	6.5×10^{-12}	4.4×10^{-6}
500	7.0×10^5	7.4×10^{-12}	2.6×10^{-7}
600	5.0×10^5	1.0×10^{-12}	1.5×10^{-8}

5.3 The Sun and the Earth

Although the primary objective was really the monitoring, and not fundamental research. of solar activity and of determining the spectral flux of

the XUV radiations in wavelengths of interest for photoionization, dissociation or excitation of atmospheric constituents, a good deal of good science emerged. This was because the very high solar activity produced many severe solar flares at frequent intervals and often in close succession (as in July 1959) that in other periods would occur only rarely; because few of these were missed with the carefully pre-arranged 24 hours watch with globally distributed observatories (Indian and Japanese stations covered the night period of Western observatories); because the newly introduced riometers could detect solar proton events following such flares that would in earlier years have been unnoticed; that quick transmission of Alert systems allowed flare effects in the atmosphere, in the ionosphere, in geomagnetism and cosmic rays to be coordinated globally. Indian scientific efforts were concentrated in the following directions: (1) in providing flare patrol, both visual and radio, (2) in building up of spectra for flaretime XUV radiation, and (3) in examining Sudden Ionospheric Disturbances (SID's) and (4) effects in cosmic rays.

The IGY, in fact, began with a bang. Right on the first day as the IGY activities started the sun erupted with a flare that was one of the severest recorded during the IGY. At the NPL this was recorded on 27 and 100 KHz atmospherics as a sudden enhancement (SEA) which is shown in Figure 26.

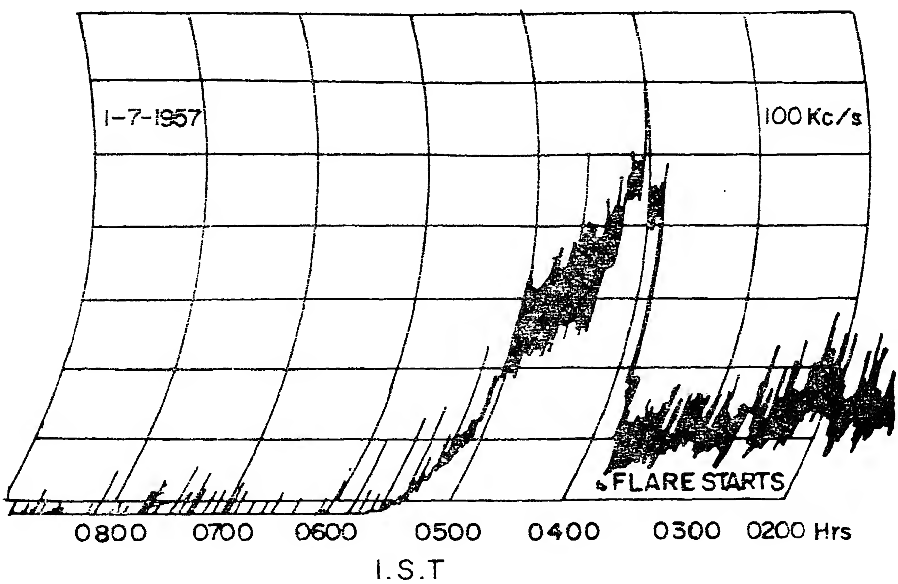


Figure 26. A severe case of SEA occurring on 100 KHz on July 1, 1957 coinciding with the beginning of IGY (after Mitra et al. 1958).

For India the optical and ionospheric effects were the primary source of data, the radio emission data being meagre and inadequate. The ionospheric effects, collectively described as *Sudden Ionospheric Disturbances* (SID), were most extensively studied. SID's were known to be a result of sudden increase in ionization, mostly in the D region, and had time curves with rapid growth and comparatively slower decay that followed the trend of the visual flare as observed in Hα with a time lag. A detailed examination of many such events by Mitra (1960) gave information on the enhancements for different classes of flares, the levels of maximum absorption causing fadeout of radiowaves, and the levels of the current systems that cause magnetic crochets. A summary of these results, shown in Table 9, after Mitra, show how surprisingly excellent estimates could be made at that time. A very useful conclusion was that the fadeout current system is located at heights around 110 km, lowering to 90-100 km during flares, but distinctly higher than the levels of fadeout absorption ($\sim$90 km) and that the ionization enhancements at levels around 70 km responsbile for reflection of VLF radio waves ($\sim$16 KHz) were considerably larger (2.5, 14 and 140 for class 1, 2 and 3 flares) than at levels around 90 km (2.5, 4.5 and 7.0 respectively). The obvious implication that radiation responsible for ionization around 70 km (X-rays <10 Å) is considerably more enhanced than radiations responsible for ionization around 90 km (EUV radiation, especially Lα) was dramatically confirmed by sunflare I and Sunflare II experiments (see later).

Detailed studies of the solar disc revealed localised magnetic fields in active areas near sunspot groups; complex systems of velocity fields were detected from doppler studies; convective motions in the sub-photospheric layers showed their presence through periodic oscillations of the solar surface. A strange feature seen was the drop in temperature from the surface value of 6000 K to about 4000 K at the interface region between photosphere and chromosphere; from thereon there is a continuous increase in temperature till temperatures of a few million degrees are reached in the corona. At Kodaikanal the 20 feet horizontal telescope provided a detailed study of Evershed effect (first discovered in Kodaikanal). Vortex motions of gas around the sunspots were charted in a 3- dimensional flow pattern. In the lower temperature transition region between photosphere and chromosphere molecular formations of biological interest were noted: a specially fabricated double pass monochromator attached to the horizontal telescope showed absorption lines due to CH, CN, etc.

The availability of a number of radio telescopes around the globe resulted in discoveries of two new types of radio bursts (Types IV and V) in addition to those (Types I, II and III) already known. Idealized exam-

Table 9 *Summary of SID Observations (after A.P. Mitra, 1960)*

Phenomena	Freequercy	Source	SID Effects			Para-meter	Relaxtion Time (*min.*)		Remarks
			Class 1	Class 2	Class 3		t_0	tf	
SWF	4 MHz	Appleton-Piggot	* Between 5 and 10				—	—	
	SCA: 183. MHz	Shain-Mitra	2.5	4.5	7.0	Af/A_0	27	30	
	SCA: 22.4 MHz	Mitra-Sarada	Between 3 and 35				35	—	
Low level reflection	2 MHz	Gardner	Excess ionization of about 1000/cm.^{3} at 60-75 km.; $Nf/N_0 \sim 20$			—	—	—	Effect corresponding to flare causing absorption increase by a factor of 3
SPA	16 KHz	Bracewell-Straker	2	5.5	9.0	Δh (km.)	23	8 (class 2) 3 (class 3)	$\Delta h'$ not known
	40-113 KHz	Weeks	2.5	14	140	Nf/N_0	—	—	—
	75 KHz	Ross		Same			16	3	$\Delta h'$=5-8 km.
	2385 KHz	Findlay		2 to 4			—	—	$\Delta h' = -\Delta h$
SEA	27 KHz	Ellison Sachdev-Mitra		1.26			21	7	
Crochet		From McIntosh data	1.50	1.70	230	$\Delta H/H$			

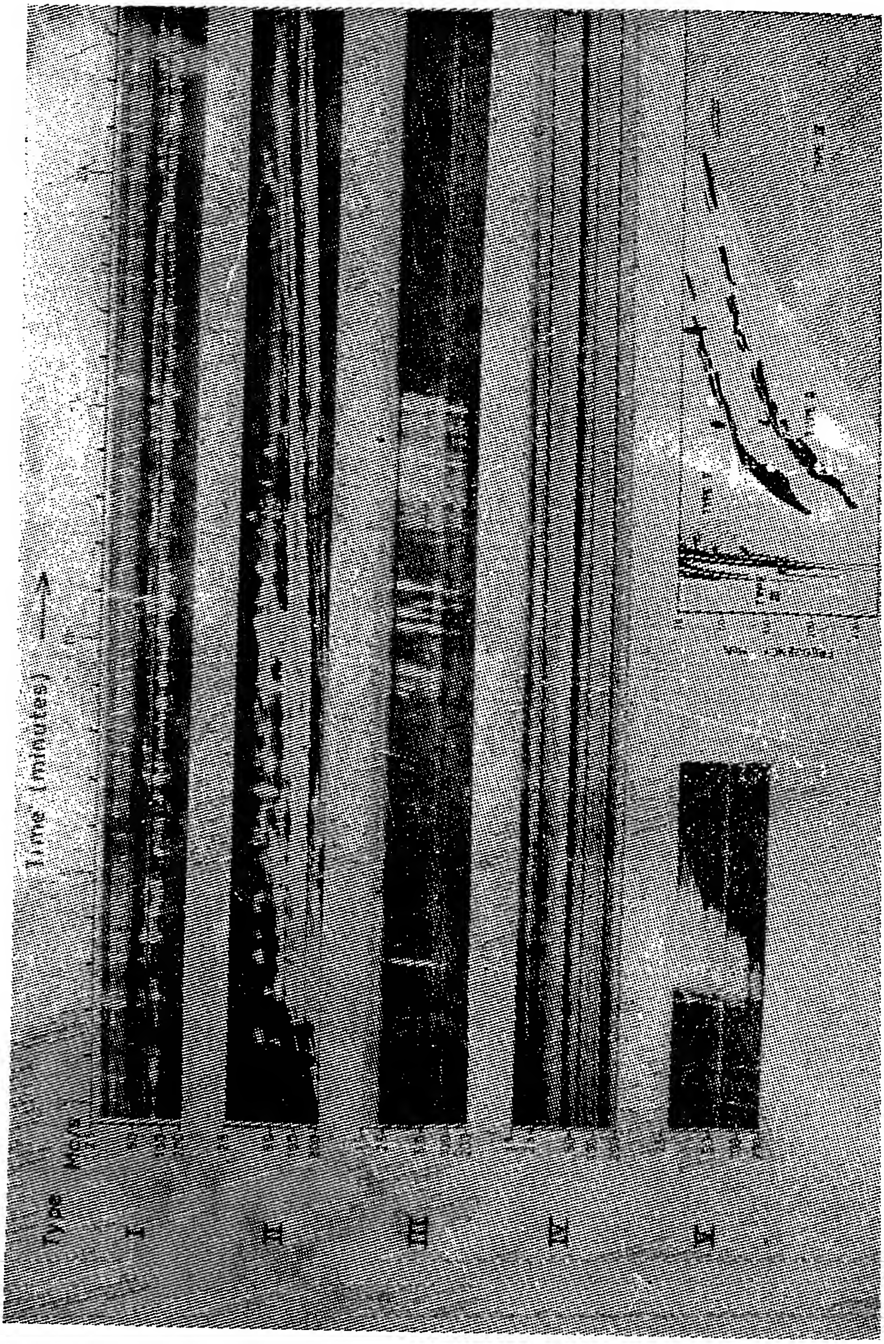


Figure 27. Idealised examples of different radio bursts (after Smerd, 1969).

ples of the different types are shown in figure 27 (Smerd, 1969). The type IV burst was originally detected with a 169 MHz interferometer (later also on spectral records between 40 and 600 MHz); this is seen only with large flares and generally follows a spectral Type II, slow drift burst. The source was seen to move outwards with a velocity of about 1000 km/s in the early stages. The activity was described with the term "long continuum". Similar long continnua in centimeter and decimeter bursts were also called Type IV bursts. The other new type was Type V which occured mainly at frequencies below 150 MHz was a "short continuum" burst, lasting for about a minute and covering a narrow band of frequencies of about 30 MHz.

We have mentioned earlier that the unprecedented high solar activity produced a rich harvest of flare—associated events. The big events tended to occur in clusters, and there were quite a few that would be considered 'large' or 'severe' or 'outstanding' under any criteria. And several criteria have since been used. One criterion, of course, was the old one, based on Hα emissions: on this criterion, 39 flares of importance $\geqslant 3$ were observed during the IGY, 33 flares of importance 3 and 6 of importance 3^+.

The second criterion was based on radio burst observations. In this the information from the Harvard and Sydney radio spectrographs was combined with the Meudon classification and list of type IV bursts prepared by Pick and Fokkers *Catalogue of Solar Radio Flares.* Around 34 large radio Flares were identified in this way.

A third criterion was to include the effect the flare event produces on the earth's ionosphere and the geomagnetic field as well as the magnitudes of cosmic ray events as seen with PCAs. About 40 severe magnetic storms with sudden cmmencements were registered; and about 22 PCA events.

The sequence of occurrence of flare event on the sun and the immediate (SID's) and the delayed effects (magnetic and ionospheric storms, PCAs, GLE's) is shown in figure. 28. The magnetic storms are associated with the arrival of solar plasma streams with velocities of about 1000 km s^{-1}; these slower particles also cause complex changes in ionospheric ionization, principally in the F region and above. These were called "*Ionospheric Storms*". PCA events require protons with energy about 10 MeV, auroral events somewhat lower. Balloons and satellites during and after the IGY confirmed the incidence of solar protons of energies > 100 MeV in the neighbourhood of the earth within a period of a few hours. But to produce an observable increase of cosmic ray at the ground, one needs much larger proton energies, from several hundreds of MeV to several BeV: these are very rare events—there was one just before the IGY, the much quoted February 23, 1956 event, but there was none during the IGY.

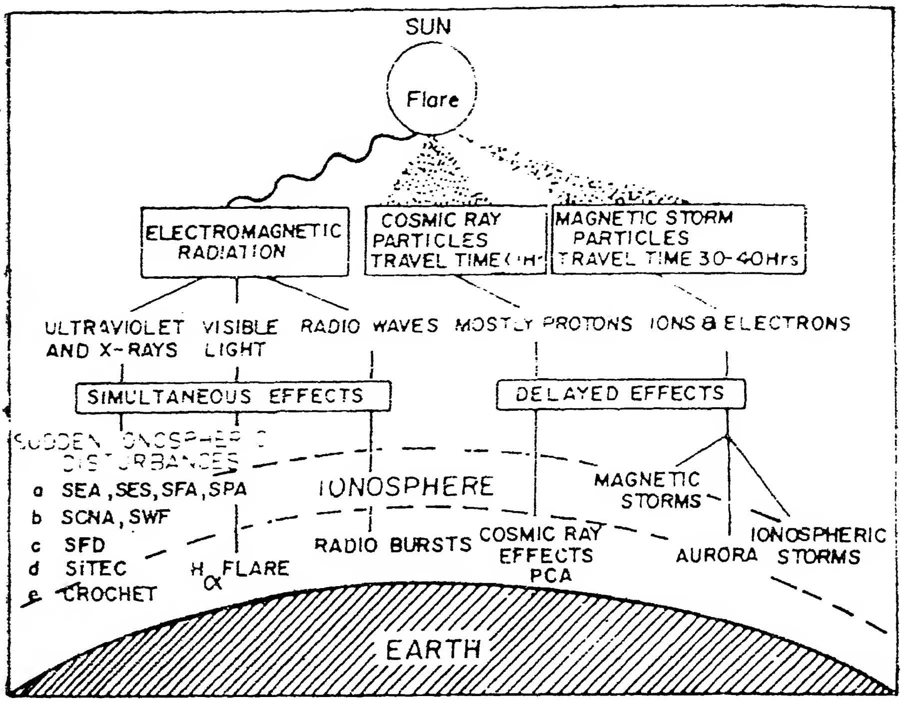


Figure 28. Sequence of a occurrence of a flare event on the sun and the immediate SID effects and the delayed effects (after A.P. Mitra, 1974).

By combining optical and radio observations on the sun with the terrestrial effects. Smerd (1969) selected *nine* large solar terrestrial disturbances during the IGY. Eight of those are included in Table 11 (double star).

On the other hand, Dodson and Hedeman (1971) identified 14 outstanding events (of index $\gg$ 13) during the IGY and 4 outstanding events during the IGC. In the Dodson-Hedeman catalogue a *comprehensive flare index* was asssigned to a flare based on five components, as follows:

(1) Importance of ionizing radiation as indicated by accompanying SID's (scale 1-3)

(2) Importance of the Hα flare (scale 1-3)

(3) Magnitude of $\sim$10 cm flux (characteristic of log of flux in units of 10^{-22} W.m^{-2} Hz^{-1})

(4) Dynamic spectra (type II=1, Continium=2, type IV of duration$>$10 min=3)

(5) Magnitude of 200 MHz flux (characteristic of log of flux in units of 10^{-22} W.m^{-2} Hz^{-1})

Table 10 *Major Magnetic Storms*

	Station	Sudden Commencement D /	Sudden Commencement H γ	Sudden Commencement Z γ	Ranges D /	Ranges H γ	Ranges Z γ	Flare Class/Date/ Starting time	Remarks
1	2	3	4	5	6	7	8	9	
Jan. 21, 1957 1253	KOD		410					SF 2+ 20/1850	
Sept. 13, 1957 0049	KOD	0.5	39	12	14	710±10	202	11/0300	
	ABG	—0.5	+17	—7	13	582	121	(Type IV burst)	
Feb. 11, 1958 0125	ANN	—3.0	—	—	18	—	—	SF2+ 9/2053 One of the	
	KOD	3	80	35	20	813	316	largest re-	
	ABG	—2 2	+80	—29	12	.668	126	corded since 1870; exceeded only by two events-March 1, 1944 (1200γ) and March 26, 1946 (1040γ)	
July 8, 1958 0748	ANN	—7.0	—	+72	15	682	127		
	KOD	4	176	58	17	710	131		
	ABG	—2.2	+95	—31	14	610	113		

(Contd, on page 82)

Table 10 *(Contd. from page 81)*

1	2	3	4	5	6	7	8	9
July 11, 1959 1628	ANN	—3.9	+113	+63	7	173(—1)	73	SF 3+ 10/0206
	KOD	2	88	46	7	168	92	Internationally
	ABG	—1.5	+ 88	—19	7	136 (3)	49	selectectd event
July 15, 1959 0802	ANN	—4.5	+132	—	15	814 (61)	212	SF 3+ 14/0332
	KOD	3	118	29	18	785	184	Internationally
	ABG	—1.1	+ 80	—18	17	751 (44)	137	selected event
July 17, 1959 1638	ANN	—5.8	+174	+96	14	362 (49)	165	SF 2 16/1604
	KOD	4	150	69	10	327	121	Internationally
	ABG	—2 7	+148	—18	11	305 (5)	73	selected event

Note: KOD Kodaikanal
ABG Alibag
ANN Annamalainagar

Events during the IGY and IGC with comprehensive index of $\geqslant 13$ are given in Table 11 alongwith observed crochets, PCA's and SCNA's. Those occuring also in the Smerd list are given in asterisks.

The Indian observations were mostly consistent with the lists but there were some outstanding events outside this list also. Table 10 gives a list of severe magnetic storms recorded at Alibag, Kodaikanal and Annamalainagar. A list of optical flares recorded during IGY-IGC at Kodaikananl and Nizamiah observatories were given in Appendix III Journal of Scientific and Industrial Research (Professor K. S. Krishnan's sixtieth Birthday number Vol. *17A* P. 106, 1958). Also included in the same are the Sudden Enhancement of Atmospherics (SEAs) observed at Delhi on 27 and 100 KHz; Sudden Cosmic Noise Absorption (SCNA) events observed at Delhi on 22.4 MHz and Mussorie on 30 MHz, and solar flare effects (magnetic crochets) observed at Alibag, Trivandrum and Annamalainagar. The SCNA events of August 3, 1957 (11.0 db at 22.4 MHz) and February 3, 1958 (11.0 db at 30 MHz) were unusually large. One large SCNA event of March 23, 1958 will be examined later in some detail.

It is a pity that beyond recording the direct or delayed effects of these very large events, not much coordinated analysis of the type later made by Mitra for events like July 7, 1966, May 23, 1967 or August 1972 (Mitra, 1974) are availabale for the events of the IGY; the sole exception was the event of July 7, 1958 which was discussed at length by Smerd (1969). This account, however, is essentially morphological. X-ray flare curves were to come later with satellite recordings of events.

The March 23, 1958 event which we shall discuss in some detail is one that is in both Smerd and Dodson-Hedeman list, was recorded optically, ionospherically and geomagnetically in India, and also happened to be one for which balloon observations of solar cosmic rays were arranged. The flare produced a severe magnetic storm with sudden commencement at 1540 hrs on March 25, signalling arrival of a cloud of solar particles at the earth. High altitude balloon flights were made near Minneapolis (55°N gm) on March 21, March 26 and April 8 to study the energy and composition of cosmic rays during the period of disturbance. The balloons carried single counters, ion chambers and photographic emulsions to measure particle fllux, atmospheric ionization and nature of the particles involved. At the NPL in New Delhi the radio flare network recorded one of the largest events ever recorded. At the peak of the flare event 22.3 MHz SCNA exceeded 13 db.

Indian observations on this event are tabulated below:

Delhi observations for this event showed some unusual features (Mitra and Sarada, 1960). Firstly, the cosmic noise absorption observed

Table 11 *Outstandings Solar Flares (Index ⩽ 13) During IGY*
(based on Dodson-Hedeman List)

Year	Time UT	Index	Crochet Alibag ($\gamma_{//}$)	Radio Burst Spectral type/ beginning time	PCA (db)	SCNA (db/MHz)	Additional Observations
1	2	3	4	5	6	7	8
1956							
Feb. 23	0331–0510	333–4			13		(S.C.)
1957							
April 17	2000–2300	33332					
*July 24	1712–1801	33332		IV: 1802,2	2 (CA)		27/1959
	1801–2025					11.0/22.4	
*Aug. 3	1024–1052						
Aug. 28	0913–1404	33332					
Aug. 31	1257–1455	33333	+17		4.9–5		2 Sept /0314
			—5				
Sept. 11	0236–0722	33323					13/0046
Sept. 18	1722–	33232					
	1815–2110						
Sept. 19	0350–0555	33333	+15			5.0/22.4	21/1006
			+12				
Oct. 20	1637–1644	33332			5.7–8		
	1644–1804						

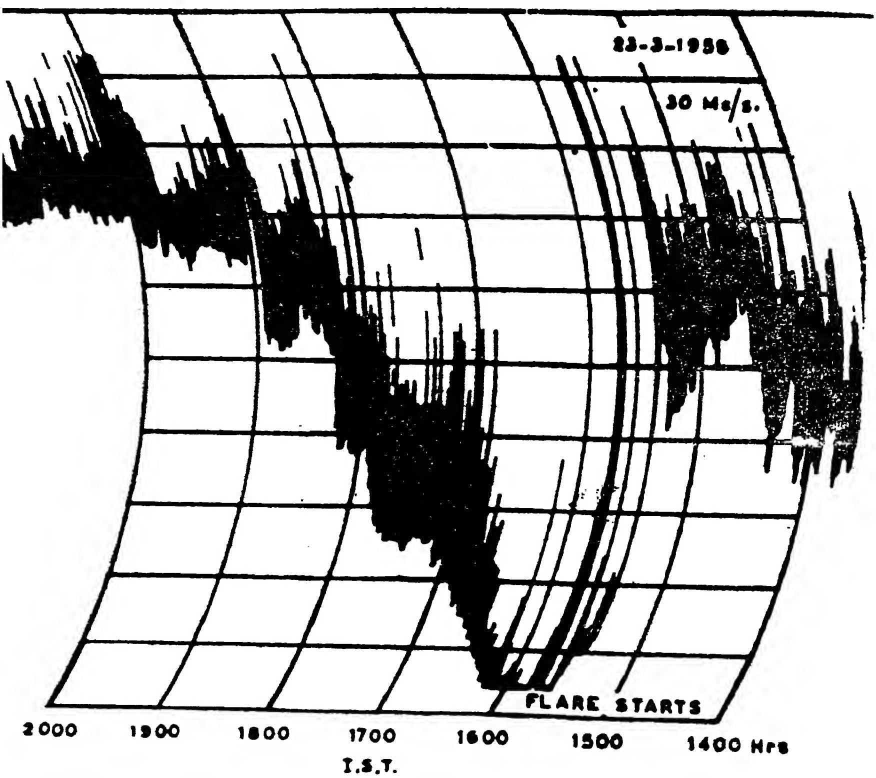
1958								
Feb. 3	1015-1048					11.0/30		
*Feb. 9	2108-2302			IV: 2116			11/0125	
March 3	1005–1411	33334	+30 —12			11.0/30		
**March 23	0947–1445	33332			12 CA	13.0/30	25/1540	
**July 7	0020–0414	33333		III 00059, II: 0101, IV; 0108 IV (V): 0027, II: 0033, IV: 0042	>15 CA	6.0/30	8/0748	
*July 29	0259–0408	33332		II 0304 IV: 0320	1.5 T		31/1529	
*Aug. 16	0433–0831	33334			>15 T		17/0622	
*Aug. 22	1428–1717	33333		IV: 1540	>10/27.6, CA		24/0140	Balloon observa-tions
*Aug. 26	0005–0124	33333		III: 0020 II: 0020 IV: 0030	>10/27.6 CA		27/0243	
1959								
May 11	2006–2150	33233			15–22 CA		12/1638	Balloon observa-tions
July 16	2114–2430	33333			15–21 CA			
Aug. 18	1014–1350	33232						
Nov. 30	0247–0356	23333						

*Included because of a major storm in India
CA : College, Alaska
T : Thule, Alaska

Table 12 *Event of March 23, 1958 details of observation*

Event	Beg.	Max.	End	Position	Size		
Optical Flare	1016	1018	1027	N18 E60	2	3.6	NIZAMIAH
	0947	1C05	1445	S14 E78	3+		
SCNA	0945	—	1245			13.90 db/30	NPL, NEW DELHI
Crochet	0954		$\Delta H=+30\gamma$	$V=-12\gamma$		ALIBAG	
			$\Delta H=+6\gamma$	$V=-8\gamma$		TRIVANDRUM	
			$\Delta H=+7\gamma$	$V=-6\gamma$		ANNAMALAI NAGAR	

was the largest recorded in this station during the entire period of the IGY and the IGC, the cosmic noise flux, at the time of the peak of the event, decreasing to levels below the threshold of the receiver (Figure 29).



A SEVERE CASE OF SCA OCCURRING ON 23 MARCH 1958, FOLLOWING A MAJOR SOLAR FLARE. THE EFFECT WAS OBSERVED FIRST AT 0300 UT

Figure 29 (a) & 29 (b) to be produced on the same page

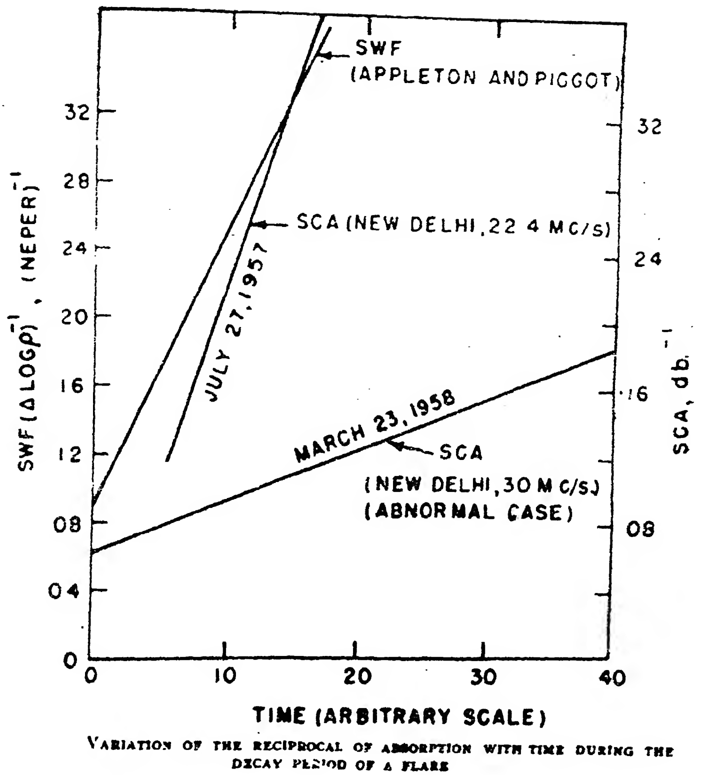


Figure 29 (b) Severe case of SCA observed on March 23, 1958 following a major solar flare and (b) variation of absorption with time during flare (after A.P. Mitra and Sarada 1960).

Secondly, analysis of the decay curves of the SCNA (Figure 29 b) showed presence of F region effect; indicating a sizable change in F region ionization. Later with the introduction of satellite radio beacon technique and incoherent radar, flare effects could be observed right from 60 to 600 km, but at that time this was unexpected; rocket measurements had not showed any increase in L_α flux, and no enhancement in the EUV region was anticipated. The results indicated, however, that such enhancements must occur—a conclusion that we now know was correct.

The University of Minnesota flew balloons on March 21 (before the flare), March 26 (during the progress of the geomagnetic storm that followed the flare) and April 8, when the disturbance effect had ceased (flights designated IGY 27, 28 and 29). The results of these flights at a pressure

level of 10 mb (102,000 ft) showed some spectacular changes. On March 26 as the balloon reached the peak level height at 1300 UT, observations of the single counter and ion chamber showed 23 % decrease of the intensities ("Forbush decrease"), followed, about an hour later, by *increase* in the particle flux and in the ionizing rate. This continued for the remainder of the flight for about six hours. The initial decrease was a consequence of the modulation of the pre-existing cosmic rays; the increase was due to the arrival of energetic solar particles (upper curves in Figure 30), mostly

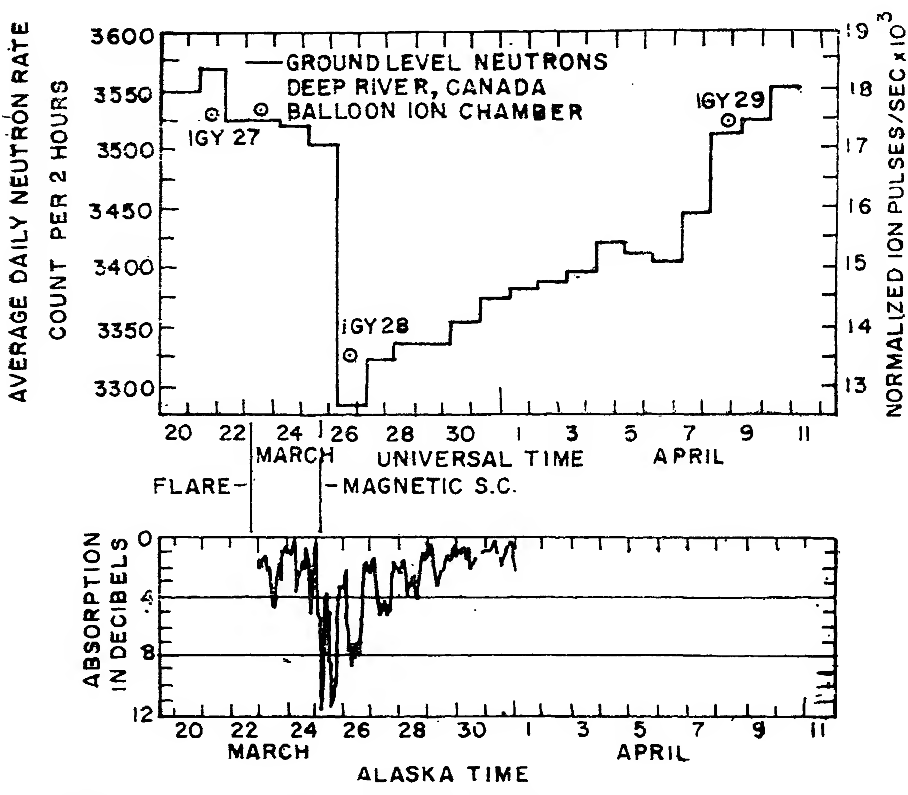


Figure 30. Upper: sealevel neutron intensity at Deep River Ontario (Canada) showing time of balloon flights and 10 g/cm² total ionization Lower: 27.6 MHz cosmic noise at Ft Yukon Alaska. (courtesy: H. Leinbach and G. Reid).

protons (there was no change in α particles), by an amount nearly half the total primary flux: the measurements were in the range 120-180 MeV. The arrival of charged particles was clear from the riometers absorption event which showed a large absorption of about 10 db on March 26 with

the onset of the sudden commencement, and the fact they were observed only when the earth entered the solar beam at 1540 UT on March 25 showed that these were solar.

The IGY saw a major advance in our knowledge of solar radiation during flares. Since additional ionization formed during solar flares and causing the SID's is located principally in the lower ionosphere one would expect enhancement in Lα or X-rays of wavelengths shorter than about 10Å. However, rocket observations over a number of years, and observations in satellite during IGY failed to indicate any appreciable change in Lα intensity. On the other hand, there was a considerable body of evidence for enhanced emission of X-rays below 10Å.

The Sunflare I experiments covering 13 rocket flights during the period July 1, 1957 to September 18, 1957, and the Sunflare II experiments covering 12 flights from July 14, 1959 to September 1, 1959 provided quantitative estimates of such measurements. Both series were conducted by the U.S. Naval Research Laboratory. The total X-ray flux for a class I flare was about 10^{-3} ergs/cm²/sec. and about 10^{-2} ergs/cm²/sec. for a class 2 flare. An average of several flares, mainly class 2 and 3, yielded the values given in Table 13. The total X-ray flux affecting the E region during class

Table 13 *X-ray Energies for an Average Strong Flare*

Wavelength Range Å	Eneygy Erg/cm²/s	Solar flare type	Remark
20–100	2	Av. of class 2 and class 1	Sunflare I expts.
80–20	3×10^{-2}	do	do
2–8	10^{-2}	do	do
0 41–0.14	10^{-5}	do	Sunflare II expts

2+ flare was roughly twice the quiet-sun value. Two points need special mention: first, more important than the ehancement of emission was the gradual hardening of X-ray during flares; secondly, while in general, X-ray emission was observed in the range of 2-8Å, still harder electromagnetic radiation (with wavelengths as low as 0.6—0.01 Å) was also observed.

There was also an attempt by the Indian scientists to develop flare time ionization models for the D region based either solely on X-ray

emission or on a combination of $L\alpha$ and X-ray emission. One such example (after Mitra, 1960) is given in Figure 31; it was clear that the

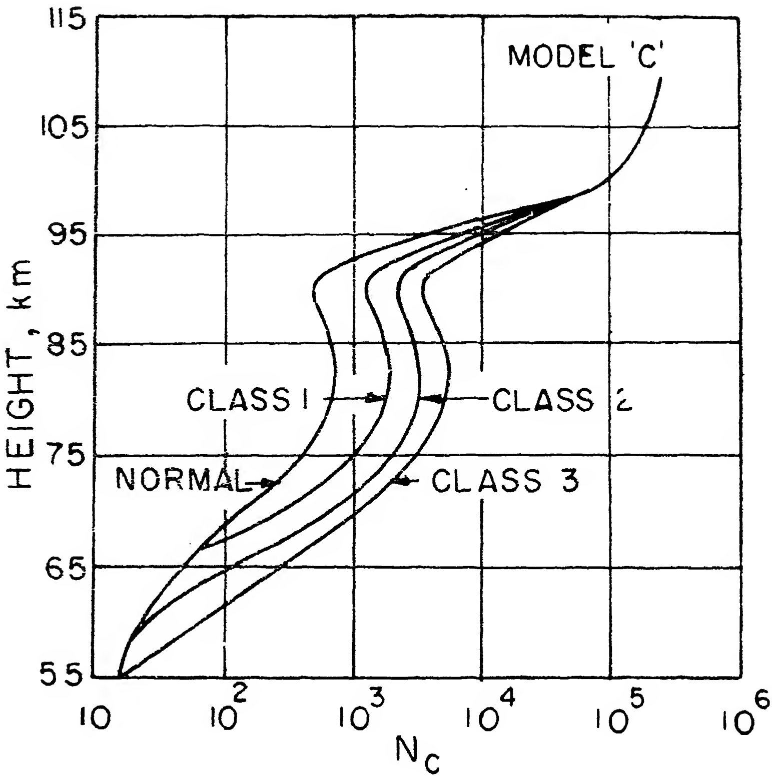


Figure 31. Distribution of flare Ionization for different types of solar flares computed by Mitra (1960)

ionization enhancements are adequate to produce the observed SID effects.

5.4 Meteorology

Of the many advances in atmospheric physics, perhaps the most important was the extension of the coverage to stratospheric heights; this became possible with the largescale use of rodiosondes globally during the IGY. In Australia at Melbourne, balloons using a valve device, made from a pingpong ball, often reached heights upto 120,000 ft; these detected the existence of an easterly jet stream between 110,000 and 120,000 ft moving at surprisingly high speeds of 90 knots. Over the Antarctica a second tropospause was detected at heights between 50 and 20 mb levels (19-20 km).

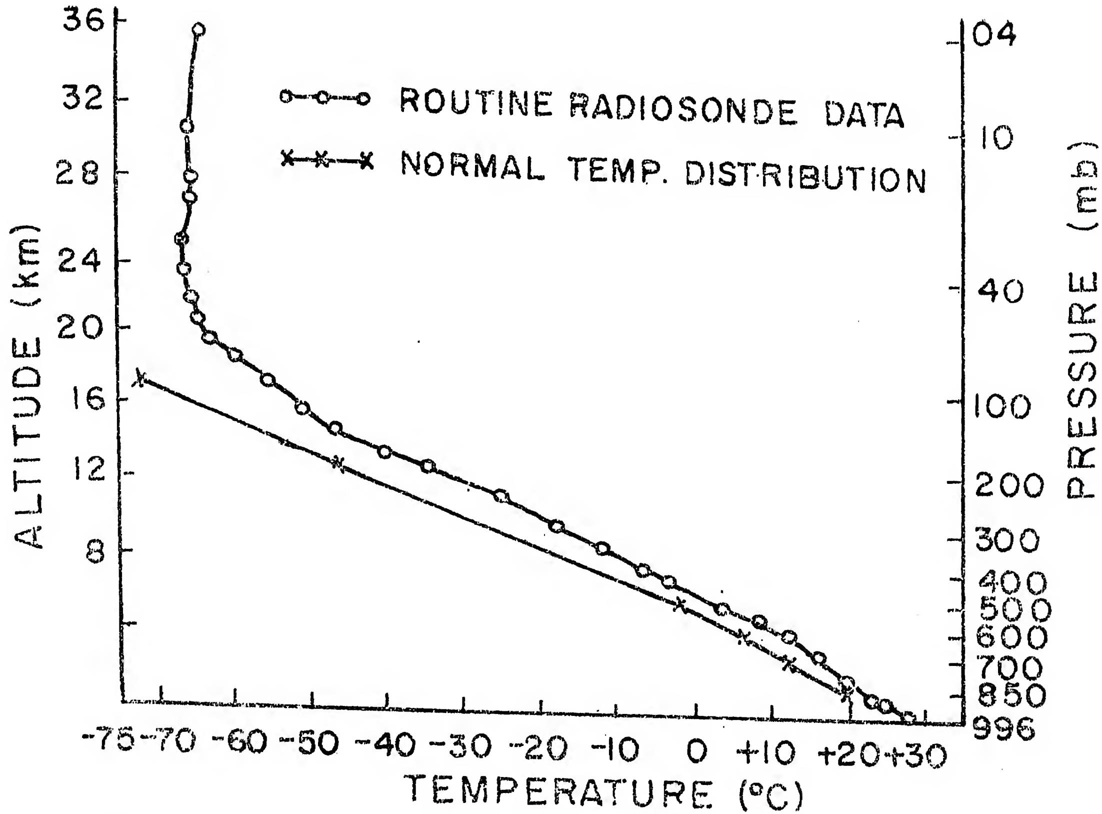


Figure 32. Temperature altitude curve for the radiosonde ascent at Dum Dum on 6 July 1957 at 0530 IST. Normal temperature distribution over Dum Dum in July and also the winds as obtained from RAWIN ascent at 0530 IST on 6 July 1957 are also shown. (after De, 1958).

In India IMD chronometric radiosondes model III sometimes reached levels as high as 4 mb ($\approx$36 km). An example of such a high altitude radiosonde flight over Dum Dum on 6th July, 1957, (De, 1958) alongwith rawinsonde which went only upto 400 mb is shown in Figure 32. The tropopause height was unusually high ($\sim$19·5 km), and the temperature was nearly constant between 19·5 and 36 km.

5.4.1 Standard Atmosphere for the Tropics

In India Pisharoty (1959) prepared a *Standard Atmosphere for Tropics* (m.s.l. to 20 km) (SAAT) as well as a slightly different *Standard Atmosphere for the Tropics for Universal use* (*SATU*), using the mean geopotential heights and temperatures of the standard isobaric surfaces over the Asian, the Caribbean and South-west Pacific areas. The standard Atmosphere was presented for the latitude range 25°N to 25°S, and were intended to replace the then widely used NACA (sometimes called the US Standard Atmosphere) and ICAO atmospheres which were primarily based on data obtained at middle latitudes in the Northern Hemisphere.

The stations used were:

Indian Subcontinent

Port Blair	(1°40′ N, 92°43 ′E)
Madras	(13°00′ N, 80°11 ′E)
Trivandrum	(08°30′ N, 76°59 ′E)
Visakapatnam	(17°42′ N, 83°18′ ′E)

Mean latitude=12°32′ N

Outside India

Bangkok	(13°44′ N, 100°30′ E)
Saigon	(10°49′ N, 106°40′ E)
Songkla	(7°11′ N, 100°37′ E)
Aden	(12°50 ′N, 45°01′ E)

The main specifications of SAAT as against ICAO/ICAN as well as the suggested III model for tropical regions were in Table 14.

One should note that a major departure was the realisation (and inclusion in the model) of a *reverse lapse rate* (i.e. *increase* in temperature) above the tropopause rather than an isothermal stratosphere. The considerably higher tropopause level was also acknowledged.

Standard reference atmospheres for tropical regions have since been derived by many groups. The ones we would particularly consider in this connection are these by Stanford Research Institute Reference Atmosphere for Tropical Regions (Hake, 1973) and the recently constructed Standard

Table 14 *Model Specification for Standard Atmosphere*

	ISTA 1 Anantasayanam & Narasimha (1979)	*ICAO/ICAN* 40°N	*US Weather Bureau*	*Asian Tropics (SAAT)* *Pisarothy (1959)*	*SATU* *Pisarothy (1959)*
Mean Sealevel pressure	1005 mb	1013.25 mb	1013.25 mb	1013.25 mb	1013.25 mb
T (m.s.l.)	300 K	288 K	300 K	300 K	300 K
Lapse rate	6.5 K/km	6.5 K/km upto 11 km	i) 5.4 K/km upto 8 km ii) 6.5K/km (8-15 km)	i) 5.4 K/km upto 5 km (Freezing level at 5 km) ii) 6.5 K/km (5-17 km)	i) 5.4 K/km upto 5 km ii) 7K/km (5-16 km)
Tropopause	16 km	11 km	15 km	17km	16 km
Temperature at tropopause	199 K	216.5 K	200.5 K	195 K	196 K
Above tropopause	—2.5 K/km T(20)=209 K	Constant above tropopause upto 20 km	Isothermal stratosphere	Reverse lapse rate of 3°K/ km above tropoapuse T (20 Km) = 206 K	Reverse lapse rate of 2K/km

Atmosphere developed for the Indian subcontinent by Narasimha and Ananthasayanan (1979). The latter distribution is also shown in Figure 33 as comparison to the early IGY model of Pishority.

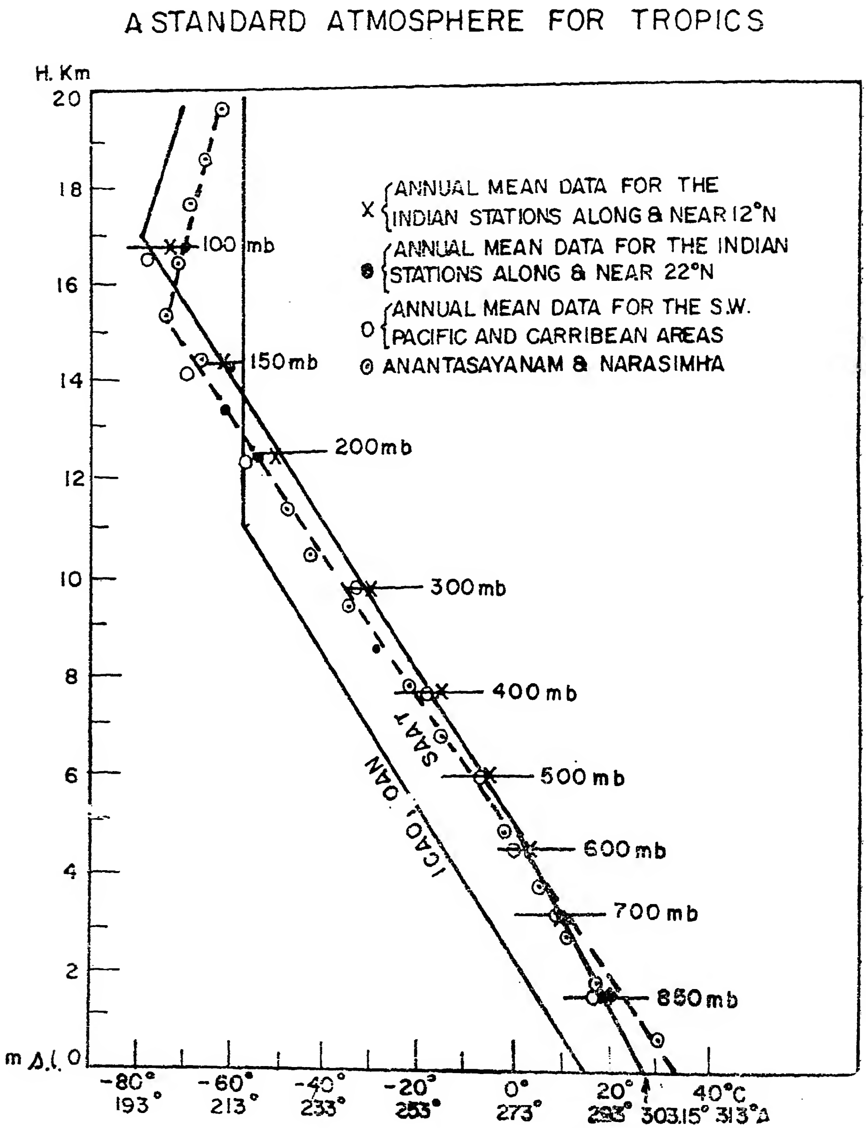


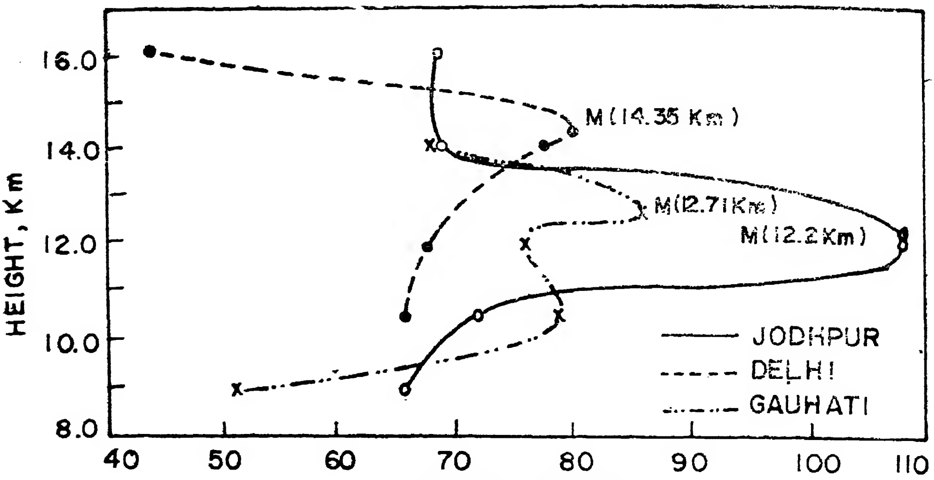
Figure 33. Height-temperature in the proposed standard atmosphere for the Asian Tropics (SAAT) and in the ICAO (ICAN) atmosphere. Also shown in dotted line is the proposed recent model of Anantasayanam and Narasimha.

5.4.3 Jet stream

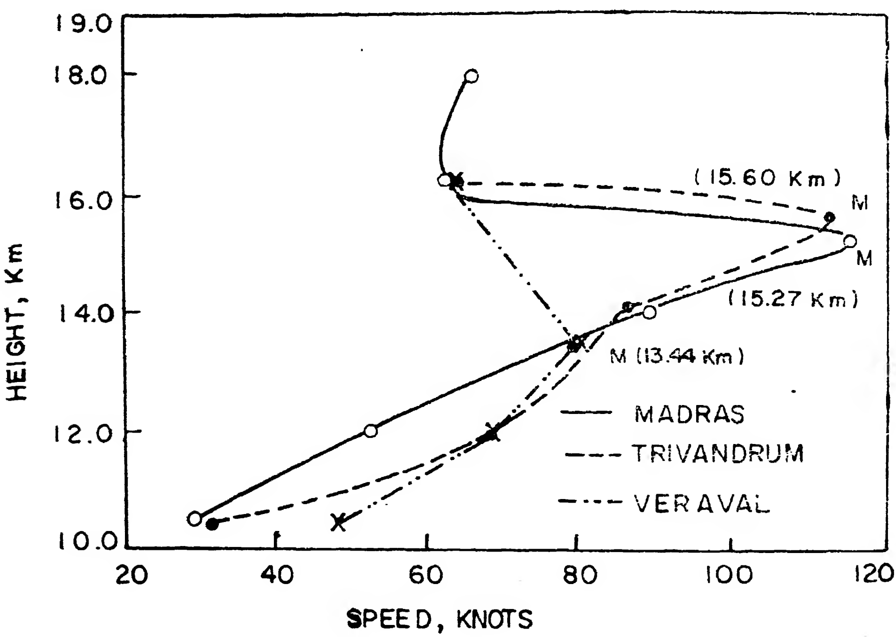
On the jet stream, a matter of special study during the IGY, the Indian observations with radiosondes, rawin and pilot balloon soundings (alongwith upper air data for Tashkent, Peshawar and Colombo) yielded results of some interest. At upper tropospheric levels spectacular seasonal changes were seen to take place. The westerlies and easterlies alternately predominated: easterlies during the monsoon season and westerlies during dry season. The westerlies strengthened and concentrated into jet streams during winter with core around 27°N and maximum around 12 km. The easterlies similarly formed into an easterly jet during monsoons. Examples of jet streams for the two seasons, as given by Pant (1963), are given in Figure 34. For the case of January 20 the jet wind peaked around 12 km with its core south of Delhi, the horizontal shears being 20 knots/1° latitude on the cyclonic side and 10 knots/1° on the anticyclonic side. At Jodhpur double tropopause with low transition around 230 mb was observed. The other figure shows one of the few cases observed of an easterly jet stream. Easterly jet streams occurred at higher levels in this case around 15 km. These jet streams occurred only in July and August, with core around 15°N.

The important roles played by minor species for climatic changes had not yet been recognized. However, *three* particular minor species were even then considered to be of significance: *water vapour*, *ozone* and *carbon dioxide*. For these, global distribution of the species content as well as their vertical distributions were derived from the network established during the IGY.

For ozone, the question of largescale global changes through human activities had not yet been brought up, nor the "greenhouse" effect of this species. However, it was recognised that the departure of the photochemical distribution from that actually observed would allow estimates of the motions of the atmosphere, since the photochemical distributions would have prevailed if the atmosphere were at rest. For this comparison to be made in reliable quantitative terms, one must have two sets of values: (a) estimates of the production function of O_3 in the stratosphere as a function of the year, and (b) measurements giving height distributions of O_3. For the first, there were several assumptions: reaction scheme deciding the formation and destruction of ozone, flux values on the relevant region of the ultraviolet spectrum and the rate coefficients for the various reactions. For the latter, since Dobson spectrophotometers merely provide values of total ozone, these could be directly used: vertical profiles could be and were, indeed, derived from Unkher method; these were however, not accurate enough for deduction of vertical motions. A



(a)



(b)

Figure 34. Variation of wind speed with height at a few stations (a) on January 20, 1958 at 1200 hours GMT and (b) on July 21, 1957 at 1200 hours GMT. (After Pant, 1963).

new and more accurate set of values became available once ozone sondes were developed.

Figure 35 gives, after Bolin (1964), a comparison of photochemical calculations (London et al 1962, solid lines) with observed distributions of ozone (Paetzold and Piscalar, 1961, dashed lines). Paetzold et al were able to construct a meridional cross section of the ozone distribution from pole to equator for the two extreme seasons: spring and fall.

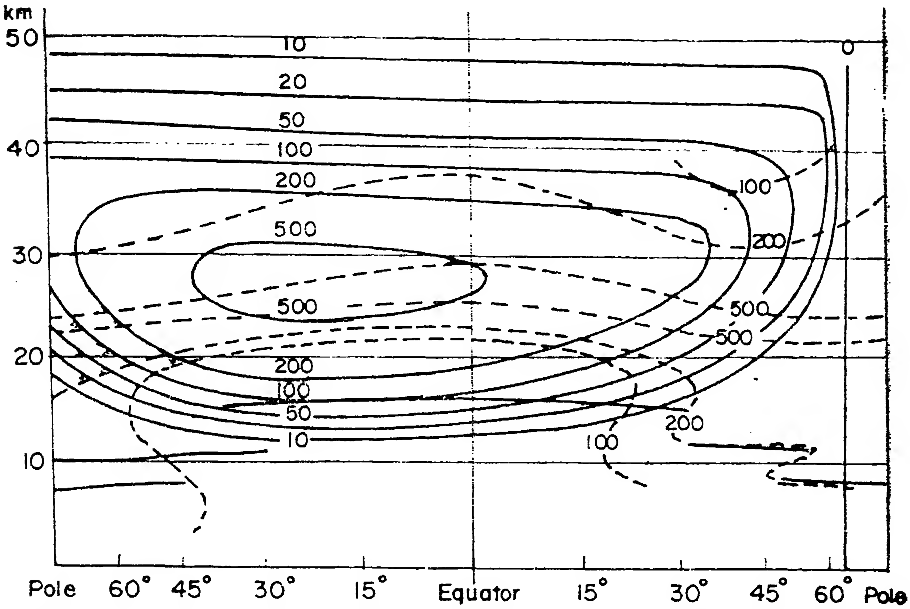


Figure 35. The photochemical equilibrium distribution for ozone (solid lines; unit: 10^{10} molecules/cm^2) in winter (right side of the diagram) and summer (left side of the diagram according to London et al (1962). The observed distribution of ozone (dashed lines) in spring (right side of the diagram) and far left side of the diagram according to Paetzold and Piscalar (1961).

There were several uncertainties in this comparison. Photochemical distributions were difficult to derive at those times: calculations were made mostly with tne Chapman cycle as follows:

$$O_2 + h\nu \xrightarrow{2424\text{Å}} O + O$$

$$O + O_2 + M \longrightarrow O_3 + M$$

$$O_3 + h\nu \xrightarrow{\lambda < 11{,}800\text{Å}} O + O_2$$

$$O + O_3 \longrightarrow 2\,O_3$$

It was already recognized that other reactions enter into ozone photochemistry. The so-called "wet chemistry" had already been introduced by Bates and Nicolet (1950), and the significance of the role of OH produced through the reaction:

$$H_2O + O(^1D) \rightarrow 2\,OH$$

had been emphasised. However, it was not possible to include these reactions appropriately O (^{1}D) productions could not be calculated properly. Nor was the role played by NOx family then known. Consequently photochemical distributions were far from those that we now derive. Novertheless, the differences between the observed and theoretical values were substantial and showed the role of dynamics.

Even on total ozone the discrepencies were obvious. The low ozone content at equatorial latitudes where production is the largest, and the very high contents at high latitudes (the largest amount in the Northern Hemisphere was found to be 500 Dobson units near 80°N in March) were clear evidences of the predominant role of atmosphere dynamics. Zonally averaged distributions of total ozone (in 10^{-3} cm, STP), adapted from London (1962) and Godson (1960) by Teweles (1964) are shown in Figure 36. The differences were explained in terms of horizontal eddy motions (and not vertical motions *in situ*). A positive covariance between northward motion and high ozone content (similar to northward motion and high temperature) was suggested. It was believed that sensible heat and ozone are both products of the same mechanism in the upper stratosphere.

Indian observations on ozone (over Srinagar 34°N, Delhi 28.5°N, Mt. Abu 24°N and Kodaikanal 10°N) showed several interesting results; although most studies were primarily morphological. Large day-to-day fluctuations in ozone content were noticed; the largest fluctuations were in January-March and were believed to be associated with western disturbances. Another interesting result was the low ozone values for Indian stations as compared to Japanese stations with nearly the same latitudes. This come from a comparison of: (a) Mt. Abu (24.6°N) and Marcus Island (24.3°S) and (b) Tateno in Japan (36°N) and Srinagar (34°N). This Compa rison is shown in Figure 37 (after Shah 1961). These lower values were attributed to the Indian summer monsoon and the Himalayas throwing up a large quantity of water vapour into the upper troposphere and lower stratosphere which would have a depleting influence on ozone concentration in the monsoon region south of the Himalayas.

The second minor species comprehensively investigated was water vapour. Here again the major thrust was the vertical distribution. Only a few such distributions were available and these mostly from middle lati-

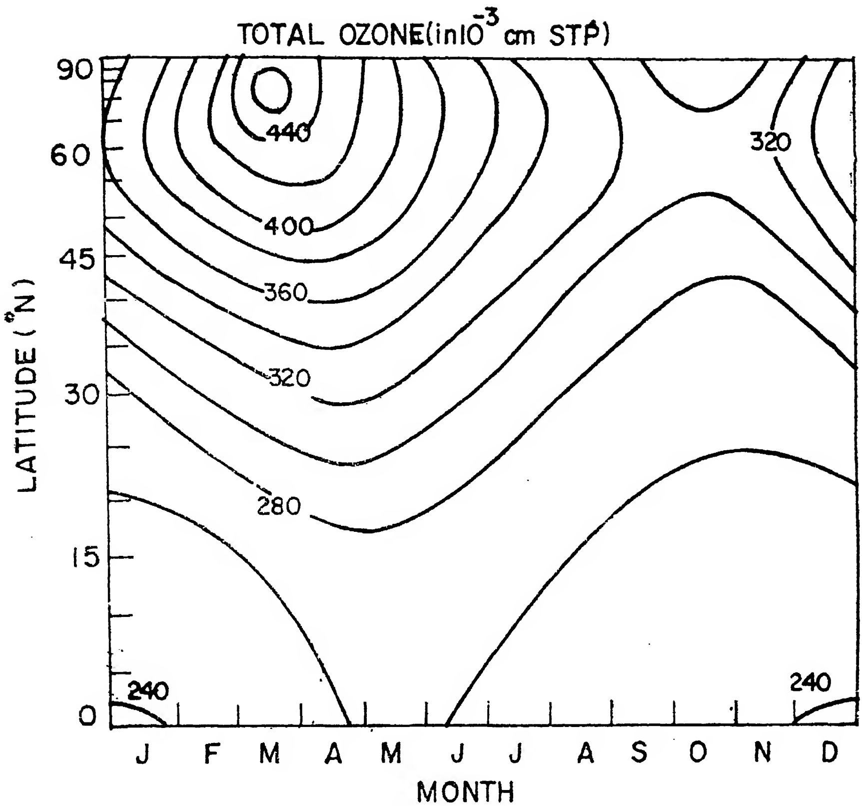


Figure 36. Zonally averaged distribution of total ozone in 10^{-3} cm STP) by months adapted from London (1962) and Godson (1960).

tudes. An average distributions summerised by Gutnick (1962) is shown in Figure 38. The mixing ratio showed a minimum at about 16 km with a value of 10 ppmv and an increase above that height. The increase had even then been questioned (Mastenbrook, 1963). Most present observations on H_2O mixing ratio show an essentially constant mixing ratio above tropopause of a round 3-6 ppmV right upto mesosphere, although a stratospheric "bulge" has sometimes been observed. Current observations on H_2O mixing ratio are superimposed on Gutnick's diagram for comparision.

It is unfortunate that no observations were undertaken on stratospheric H_2O by scientists in India during the IGY or since. Observations In India continue still to be limited to radiosonde observations in the lower troposphere and the few stratospheric observations over India are those by others : Murcray in *1963* with a ballon-borne IR system showing

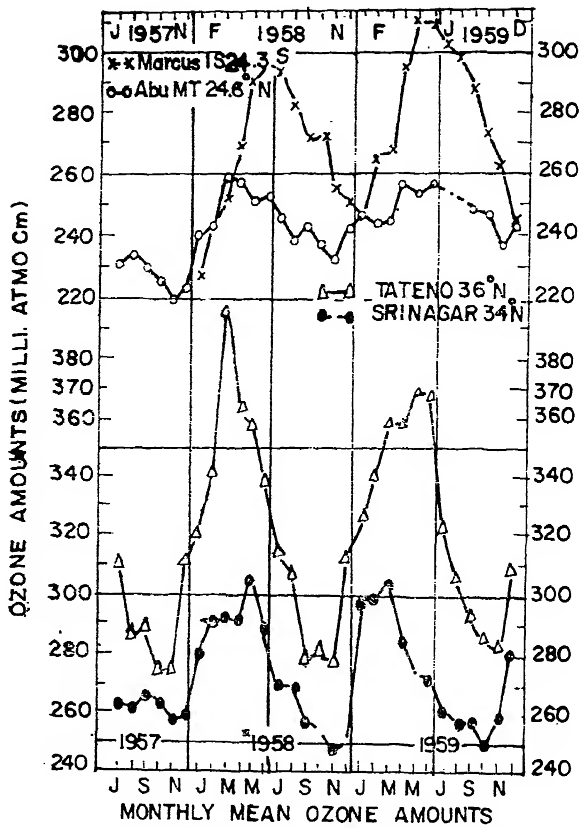


Figure 37. Monthly mean ozone amounts at (i) Marcus Island and Mt. Abu and Srinagar and Tateno (after Shah, 1961).

a very dry stratosphere and the recent observations by USSR scientists with rocketborne instruments over Thumba.

The third minor constituent on which some attention was given during the IGY was carbon dioxide. It was already known that the atmospheric CO_2 content had been continually rising due to increasing use of fossil fuels (a problem that is now taken to be one of the most serious threats to the climatic stability). The IGY-time atmosphere contained approximately 315 ppm of CO_2 with an annual increase of about 0.7 ppm (Bolin and Keeling, 1963) although fossil fuel conbustion added annually 1.6 ppm of CO_2. The rest was assumed to be absorbed by oceans. Seasonal variations that were observed were attributed to the assimilation of CO_2 in northern latitudes in summer and release due to decay of organic materials during the rest of the year.

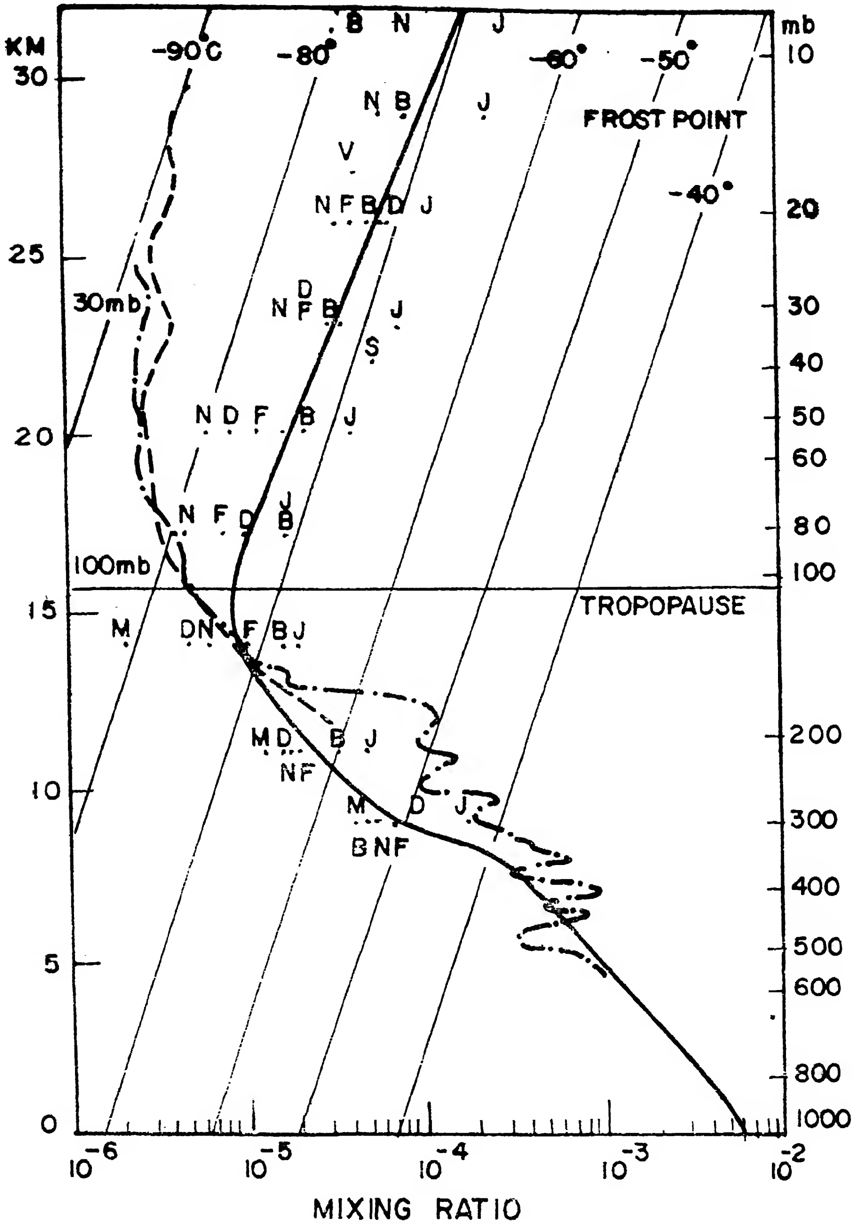


Figure 38. The average distribution of water vapour as a function of height in middle latitude expressed as mixing ratio to dry air. Code B, U, S. Ballistic Research Laboratories; N, Naval Research Laboratory, US; F, University of Denver (spectroscopic); D, University of Denver, (front point); J, Japan Meteorological Agency; M. Meteorological Research Flight, UK; V, Vapour trap measurements; S. Molecular sieve; X. mean of all measurements. Also included measurements over Palestine, Texas on November 8, 1978 by two balloon flights.

5.4.3 Stratospheric Wärming

Two of the most significant findings were related to (i) discovery of stratospheric warming and (2) quasi-biennial oscillation (QBO) with a period of about 26 months.

Reversal of stratospheric circulation from easterlies in summer to westerlies in winter was known before 1957, but details of the transition were inadequately available. An exciting wintertime phenomenon—*sudden stratospheric warming*—was discovered as early as 1952 by Scherhag. During IGY, two stratospheric warmings occurred: one in January 1957, the second in January 1958. For the 1958 warming the data for the first time, thanks to coordinated IGy efforts, were comprehensive. Preparation of 10 mb and 30 mb charts became feasible. Also with the availability of rocketborne equipments, one could have a glimpse of even higher highests. For the January 1958 event, polar westerlies were well-developed at 10 mb by mid-December 1957 (Figure 39). Rocket grenade measurements showed that these westerlies extended to 60 km, beyond which the wind degenerated into turbulence. The breakdown of westerlies occurred in late January 1958. On January 27, 1958, two rocket flights (Jones et al, 1959) showed a sudden temperature rise from about 235 K at 75 km to 250 K at 80 km. Two days later rocket measurements of atmospheric density over Fort Churchill indicated a large increase of temperature around 30-45 km, but none at lower levels. In a few more days some warming was observed at stratospheric height. It was clearly established that the breakdown in stratospheric circulation and the accompanying warming were preceded by a breakdown of stratospheric circulation throughout the mesosphere.

The 26-month QBO was discovered at the end of the IGY. It was first observed (Figure 40) above the equator by Reed and Rogers (1962) in the zonal flow at heights of 20-30 km. Subsequent work (Figure 40) by Angell and Korshover (1963) showed that QBO exists also at high latitudes. However, these is a nodal region and a change in phase around 25-34°N.

5.5 Cosmic Rays

5.5.1 Van Allen Belts

The most spectacular event in the field of cosmic rays was the discovery of intense layers of radiation belts by Van Allen in USA and Vernov in USSR. The first indication was the discovery by the US satellite Explorer I of radiation of rapidly increasing intensity above. 100 km. The observations by Pioneer III space rocket (Figure 41) showed that the layer actually contains two separate zones centred around 13,000 km and 23,000 km

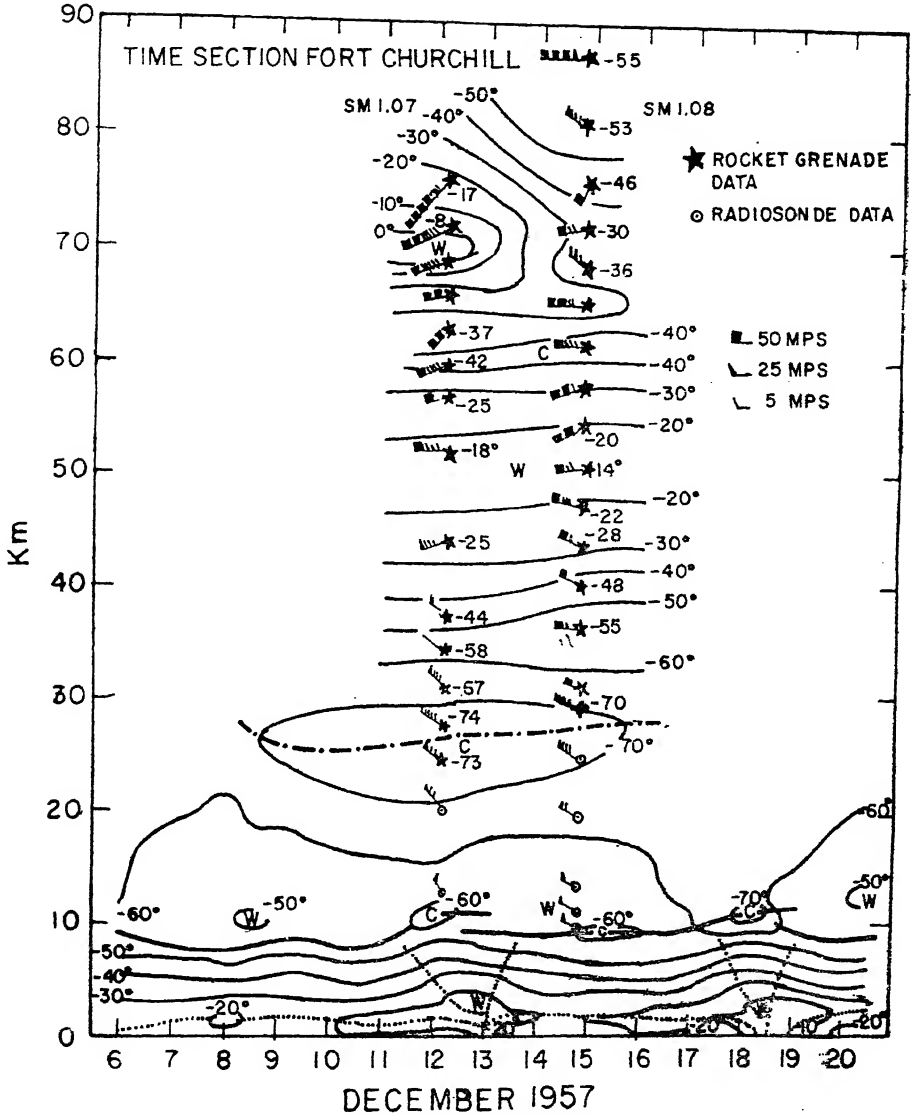


Figure 39. Time section for Churchill, 6-20 December, 1957. Rocket grenade experiments (Stroud et al, 1960) were at 0400 GMT 12 December and at 2100 GMT, 14 December, Temperature analysis in °C (based on rawinsonde data below 30 km); grenade temperatures are entered at data points. Fronts given by dotted lines, tropopause by heavy line, thermal boundary by dashed-dot line. Letters C and W indicate cold and warm areas of diagram respectively. Barbs represent wind speed are placed at the tailend of the wind shafts; shaft pointing towards lower right of diagram represent wind from the northwest (from Tewles 1961).

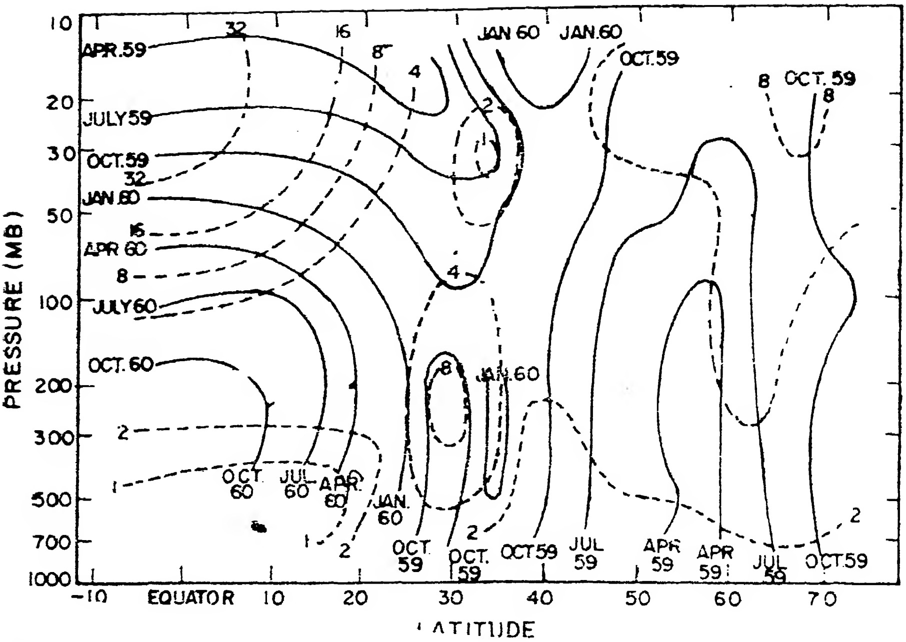
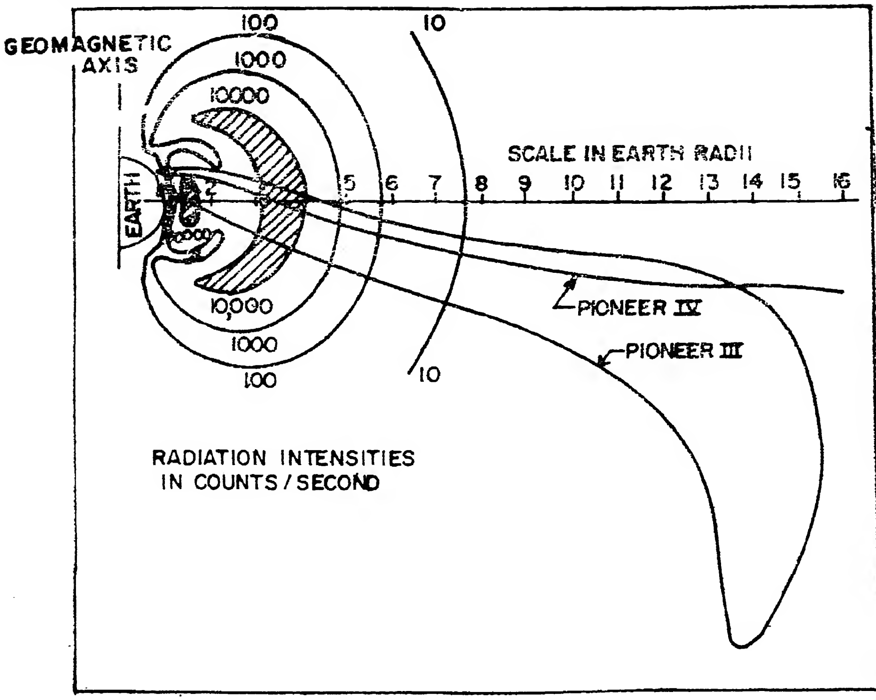


Figure 40. The time solid lines and amplitude (dashed lines, in kt) of minimum east wind (maximum west wind) for the 26 month zonal wind oscillation as a function of latitude and pressure based on stations in the Pacific Ocean area (Angel l and Korshaver 1962).



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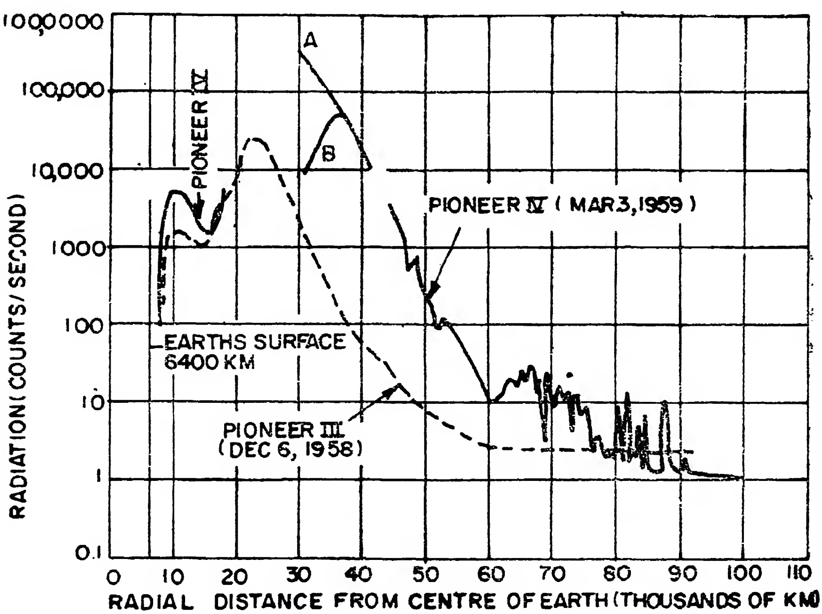

b

Figure 41. Geomagnetic projections of Pioneer III and IV (upper) trajectories superimposed on meridional profile of the Van Allen Radiation belts and (lower) comparative plots of Intensity Data from Pioneer III and IV (same scale is used for both the plots but difference in longitude ignored) (Source IGY Bulletin).

respectively. The populations of the inner zone could be divided into a soft component with energies of 100 Kev and a hard component with energies of the order of 6 MeV. The probable origin of the layers was then believed to be either the beta decay of cosmic ray into electorns and protons or injection into the upper atmosphere of streams of particles coming from the sun. These charged particles may then be trapped in orbits around the earth. In these trapped orbits they spiral about the magnetic lines of force in the manner of a helix going back and forth between north and south magnetic poles. Since they are trapped at heights far out in space where air density is low, they have a long lifetime. With these long life times, even though the particles are fed into the layer at a very low rate, the population of particles builds up to substantial values. This was believed to be the key to the formation of Van Allen layers.

Pioneer IV space probe (figure 41) that followed (launched on March 3, 1959) reaching a point 658,300 km radially from the centre of the earth, reconfirmed the existence of the trapped radiation, but found surprisingly large radiation in the outer belt (300,000 counts as against Pioneer III observations of 25,000 counts/sec on Dec. 6, 1958) as well as an extension of the belt outwards by another 15,000 km. This was attributed to the strong corpuscular emission from the sun during a geomagnetic storm that began at 0215 UT on February 25, 1959 and produced intense auroras on February 25, 26, 27, 28 and March 1. This was considered to be the most persuasive direct evidence in favour of the solar origin of at least the outer Van Allen belt.

5.5.2 Project Argus.

A remarkable project undertaken during the IGY was "*Project Argus*". In this experiment artificial radiation belts (Figure 42) were produced by three nuclear test explosions all at a nominal altitund of 480 km above earth on August 27 (0230 UT, location of the burst 38°S, 120°W,) and 30 (0320 UT, 50°S, 8°W) and September 6, 1958 (2210 UT, 50°S, 10°W) in the South Atlantic Ocean. Elaborate arrangements were made in advance to study the effects produced. The U.S. Special Weapons Centre undertook the launching of a series of high altitude rockets upto 800 km. A variety of experiments were arranged at suitable ground stations on board aircrafts and ships and, in addition, the far-flung international network of the IGY was available. Explorer IV satellite (1958 Epsilon) was launched on July 26, 1958 at 1506 UT, one month earlier, at a steep orbit of 51° to the equator to map first the intensity of the normal belts prior to explosion, and then to map the changes that occurred. Between August 27 and September 19 good data were obtained on 164 intersections of the Argus shells by 1958 epsilon.

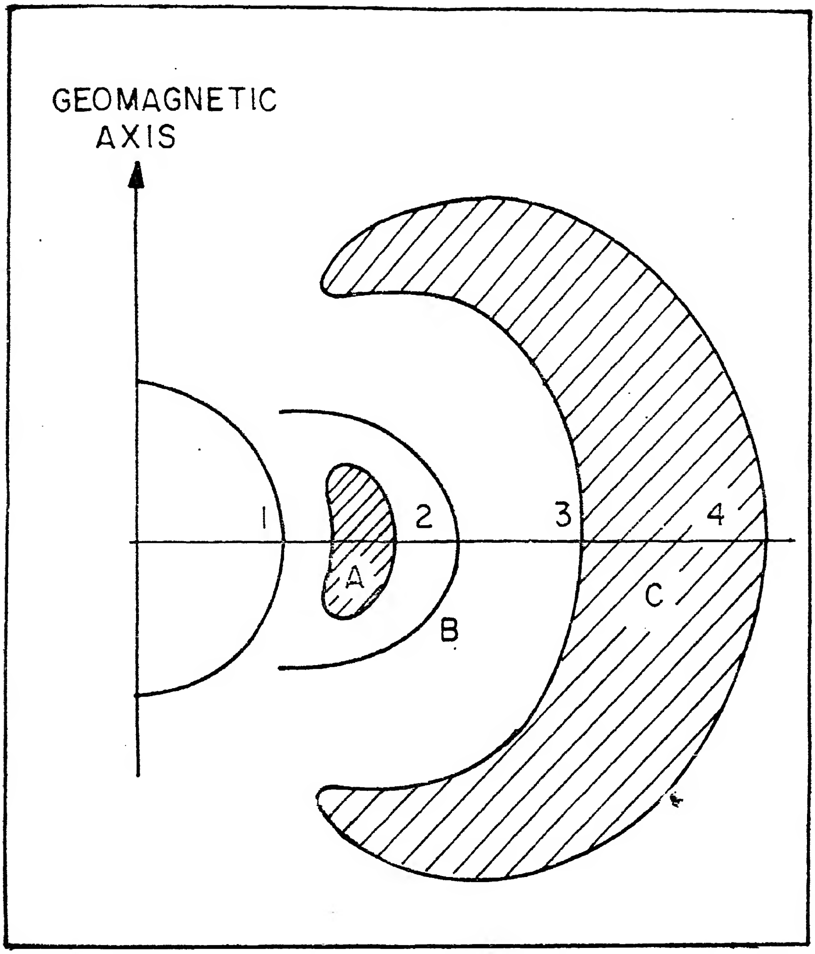

Figure 42. Approximate position of Argus shells with respect to the Van Allen Regions of trapped natural radiation. A is the inner Van Allen Belt: B is the position of Argus shells; C is the outer Van Allen Belt. (scale in earth radii (source: *IGY Bulletin*).

Following the explosions a fascinating sequence of observations was obtained. The brilliant initial flash of the explosion was followed by a fainter but persistent auroral luminescence in the atmosphere along the magnetic lines of force through the burst point. Almost simultaneously a bright auroral glow appeared at the conjugate point (near the Azores Island). In the conjugate areas radar echoes of auroras occurred within a minute of the burst and lasted in one case $1\frac{1}{2}$ hour. A new radiation belt was produced. Its nature and intensity were mapped by Explorer IV as it criss-crossed through rhe man-made belt hour after hour and day after day. The position of the new belt relative to the pre-existing belts is shown in figure 41. The lifetime of the artificial belt extended upto early December (Pioneer III detected some residual electrons on December 6, 1958) but had certainly vanished by March 1959 when Pioneer IV was not able to detect any effect. The mean thickness of Argus I+II shells (at half-maximum intensity and estimated perpendicular to shell boundaries) was about 90 km and the mean thickness of Argus III shell about 150 km. For the first time in history, measurements of geophysical phenomena on a world-wide scale were related to a quantitatively known cause-namely, the injection into the earth's magnetic field of a known quantity of electrons of known energies at a known posilion at a known time.

5.5.3 Time variations of cosmic rays

In India a major interest rested on the time variations of cosmic rays. The extent to which they are extraterrestrial in origin was not clear at that time. It was recognised that stations at low latitudes have particular advantages in resolving this problem. Since at low latitudes east-pointing, west-pointing and vertical telescopes scan the same portion of the celestial sphere, presence or absence of a difference in the time of maximum of the diurnal vatiations in the intensities observed with these telescopes clearly and unambiguously determines whether the source is *outside* or *inside* the influence of the geomagnetic field. By collecting and critically analyzing cosmic rays intensity at Ahmedabad, Trivandrum, Kodaikanal and Gulmarg in India and at Chacaltaya in Bolivia, Sarabhai and his colleagues (1961) concluded that meteorological effects could not entirely account for the observed daily variations in cosmic rays. The Ahmedabad observations consisted of directional telescope observation by Nerurkar (1956) at Ahemedabad for the years 1954-55, and for the IGY (1957-58) by directional telescopes pointing towards East and West at 45° to the zenith by Rao and Sarabhai (1961) and vertical telescopes of comparable geometry by Razdan (1960).

The arrangement of the counters in the inclined telescope was as in figure 43. Since earlier observations have shown larger amplitudes in the

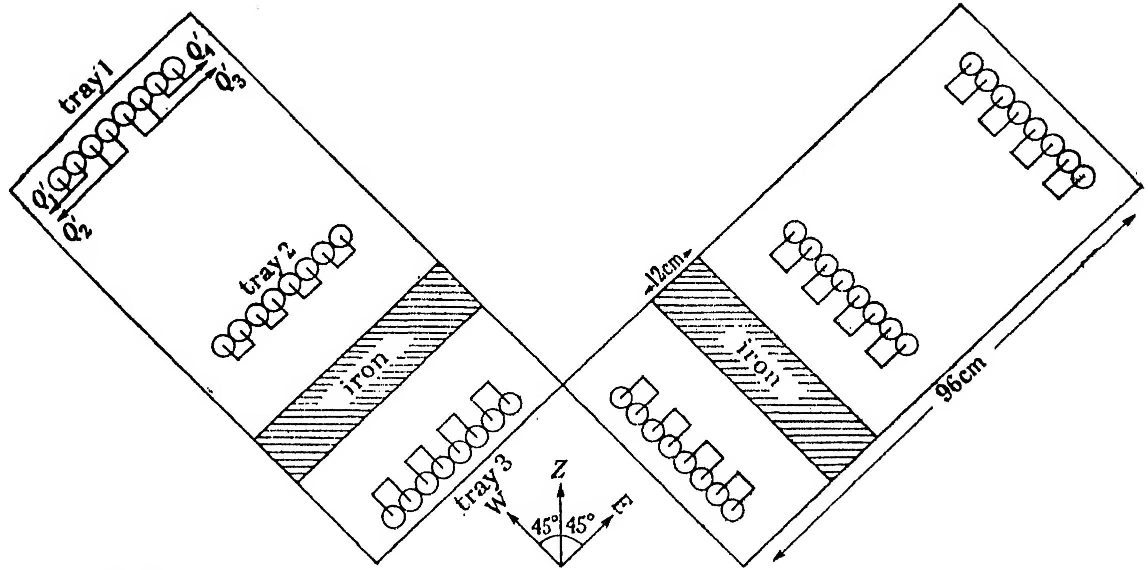

Figure 43. The arrangement of the contours in the unit consisting of inclined telescopes pointing 45°E and 45°W (after Rao and Sarabhai, 1961).

daily variation of meson intensity for a narrow angle of opening in the east-west plane compared to that measured with a wide angle of opening, telescopes with different angles of opening in the east-west plane were arranged. For Ahmedabad, the geomagnetic cut-off energies and mean primary energies of response for the telescopes were calculated to be :

	Cutt off energy	Mean energy of response
45°E	29.1 GeV	52.5 GeV
Vertical	14.6 GeV	46.5 GeV
45°W	11.2 GeV	32.5 GeV

Meteorological corrections were done with great care. For pressure corrections, a barometric coefficient of 0.22%/mm Hg was used to correct meson intensities in both east and west directions; it was assumed that there was no compelling evidence to believe a change in pressure coefficient with indication. Corrections for daily variations in temperature were considered to be important only for heights upto 2 km; amplitudes of daily variations at 1 and 2 km heights respectively were taken to be (using Beer's law) only 0.22 and 0.11 of that at surface. For monthly temperature corrections, a maximum amplitude of 0.22% was used for the late winter months of February and March, and a minimum amplitude of 0.06% during the monsoon months in July and August. The great care with which the meteorological influence was eliminated yielded some interesting conclusions. Before application of the meteorological correction the 24-month mean amplitudes of the daily variations were quite different for the west and east directions; the west amplitude being only 1/3rd of the east. After corrections were applied, they were nearly the same, thus removing an apparent anomaly in the daily variation. The differences in amplitudes for narrow and wide angle telescope also vanished.

With the meteorological influence removed, although the 24-month daily variation during 1957-58 for the east and west directions were roughly identical, there was a time difference. The relative *time difference* for the times of maxima of the diurnal variations for the East and West telescopes, when plotted for individual days showed a large scatter; with two preferred ranges, one for $\triangle t_m = 3.9$ hrs and the other for $\triangle t_m \sim 0$. This is evident in the representations giving average daily variations shown in Figure 44 (after Rao and Sarabhai 1961); the representations are for time differences between the time of diurnal maximum for the west telescope relative to that for the east, the latter assumed to be along 00 hr local time. Only for days for which the amplitudes of the diurnal variations

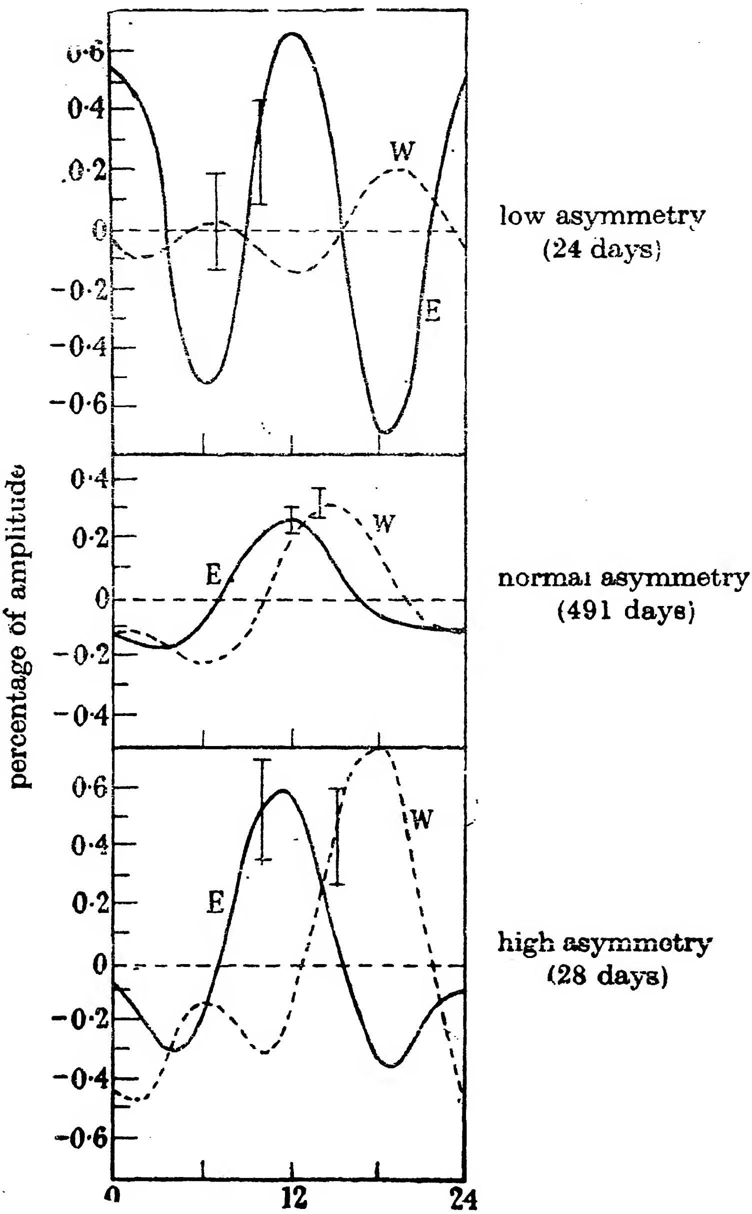

Figure 44. The average daily variation for east and west pointing telescopes during 1957 and 1958 at Ahmedabad on group of days having low, medium and high east-west asymmetry (after Rao and Sarabhai, 1961).

exceeded 2σ level were used. It was clear, therefore, that although the mean daily variation was due to an anisotropy of the primary radiation, there were days when the source of variation was located *within* the influence of the geomagnetic field (the local source). The latter occured on days of high C_p ($C_p \geqslant 1.0$) i.e. on days which were geomagnetically disturbed.

This aspect of the influence of the geomagnetic disturbance on the east-west asymmetry was then examined in detail. The geomagnetic cut-off energies in the east and west directions, it will be recalled, are different. Consequently the time variations of the east-west asymmetry defined by $100 \times 2\ (W-E)/(W+E)$ at low latitudes is essentially a measure in the changes of the primary energy spectrum. No such work relating low-latitude changes of asymmetry with changes in the energy spectrum of the primary radiation existed: the Indian work on this aspect was, therefore, the first such effort. The main thrust was to isolate *short-term* primary variations of intensity lasting from one to several days from the long-term primary variations such as the seasonal changes or variations related to 11 year changes in solar activity: the former was expected to be related to beams of ionized solar matter. To enable this separation, 15 day running averages were used and the daily departure was taken from this average. With this data treatment the Ahmedabad observations of meson intesity by directional telescopes were grouped into 3 classes: *high*, *normal* and *low* asymmetries. The high and low asymmetries were defined by deviations above and below 2T level. During 1957-58 Sarabhai and Rao found 491 days of normal asymmetry, 28 days with high asymmetry and 26 days of low asymmetry, as shown in Figure 44.

Rao and Sarabhai then proceeded to examine these different levels of asymmetry with daily mean neutron intensities at low and middle latitudes, with geomagnetic disturbances and with H. Neutron monitor stations used are listed in Table 14. The influence of the geomagnetic disturbance was clearly displayed (Figure 45). The following results emerged:

(i) Days of *high* asymmetry were days which were magnetically quiet, but occurred 3-5 days prior to the arrival on the earth of solar corpuscular streams. These were associated with enhanced mean intensity of neutrons.

(ii) *Low* asymmetry epochs occur 3-5 days after the onset of cosmic ray storms associated with SC magnetic storms. These are associated with depressed mean intensity of neutrons at all stations. Value of H, high $\sim$ 6 days before low asymmetry epochs, reached a minimum about 3 days prior to the epochs when C_p is enhanced.

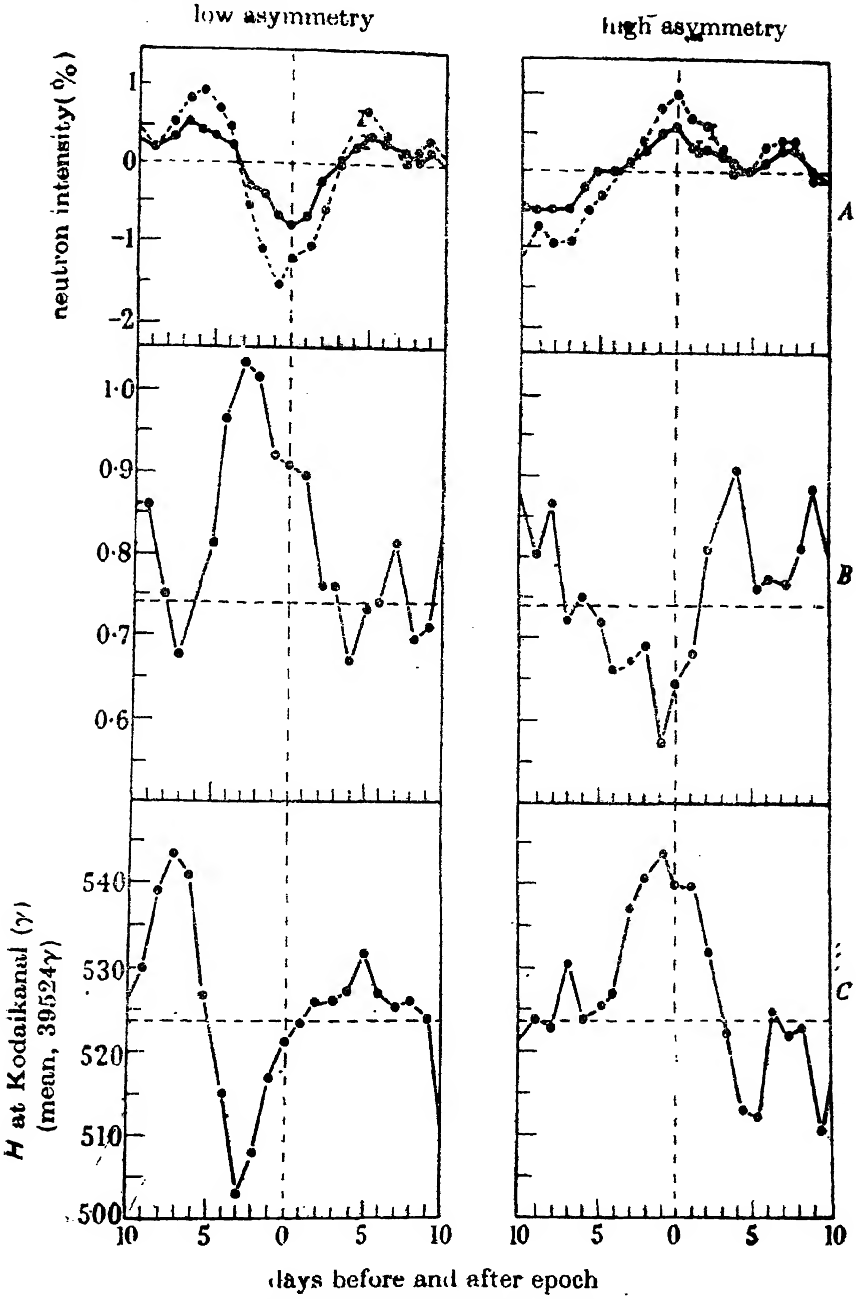

Figure 45. Chree analysis for epochs corresponding to days of low and high east-west asymmetry of (a) daily mean neutron intensity at stations situated in equatorial (—) and middle latitudes belts (. .), B C_p and (C) H, the daily mean intensity of the horizontal component of the geomagnetic field at Kodaikanal Source l (after Rao and Sarabhai, 1961).

Table 4 *Particulars of Cosmic Ray Neutron Stations used in the analysis of Rao and Sarabhai (1961)*

Station	*Altitude*	*Geomagnetic Coordinates* Lat	Long	*Investigators*
	(m)	Equatorial Stations		
Ahmedabad	s.l	13.9°	143.9°	V.A. Sarabhai, India
Huancayo	3400	–0.6°	350.8°	J.A. Simpson, Chicago
Kodaikanal	2343	0.6°	147.1°	V.A. Sarabhai, India
Lae	s.l	–16.0°	217.4°	A.G. Fenton, Hobart
Makerere College	1196	–2.0°	101.40°	D.M. Thomson, Uganda
		Mid and High Latitude Stations		
Churchill	39	68.7°	322.9°	D.C. Rose, Canada
Ottawa	101	56.8°	351.1°	D.C. Rose, Canada
Murchison Bay	s.l	72.2°	137.2°	A.E. Sandstrom, Sweden
Resolute	17	82.9°	289.3°	D.C. Rose, Canada
Mawson	s.l	–73.1°	103.8°	A.G. Fenton, Hobart
Mt. Wellington	725	–51.5°	224.5°	A.G. Fenton, Hobart

A summary of the principal conclusions arrived by Rao and Sarabhai are indicated in Table 15.

Table 15 *Sources of Time Variations of Cosmic Rays (after Rao and Sarabhai, 1961)*

	External Source	*Local Source*
West to East Ratio of diurnal amplitude	1.5±0.3	0.8±0.1
Difference between diurnal time maxima for east and west	6 h	0 h
Energy spectrum of variation	$a\epsilon^{-0.8\pm0.3}$	$a\epsilon^{0}$
Location of source with respect to earth-sun line	112±10° [outside the influence of the geomagnetic field]	0° [within the influence of the geomagnetic field]
Associated index of geomagnetic disturbance C_p	Low or medium C_p	High C_p
East-West asymmetry	Above normal	Normal

By this time there was a considerable body of evidence suggesting that interplanetry space is filled with magnetized plasma whose conditions are controlled by the sun and it was felt that the observed anisotropies are far more likely to be due to modulation by interplanetary magnetic field of an originally isotropic radiation entering the solar system from interplanetary space. Around this time Parker suggested the existence of a continuous stream of a steady plasma flowing out of the rotating sun stretching the magnetic field lines into the shape of Archimedes spiral. The directional studies of Sarabhai and his colleagues showed that this solar wind came from a direction inclined at about 45° to the East of the zenith and could be explained if the solar wind co-rotated with the sun and took the form of the spiral in the interplanetary space. Thus with the observed cosmic rays being regarded as modulation effect due to the solar wind, there now emerged a new and valuable tool for the study of electromagnetic fields and distribution of matter in interplanetary and interstellar space. This prompted efforts to identify electromagnetic states of interplanetary space through measurements made with galactic cosmic rays and disturbances in the geomagnetic fields.

In this detailed interpretation of the physical processes responsible for the anisotropies, there were several problems. The instruments responded to a very wide spectrum of energies of incoming particles. It was necessary to have a very reliable method for taking into account the effect of geomagnetic bending upon the directions of arrival of the particles. Such bending of course depended upon the energies of the particles: whereas particles of several tens of GeV could arrive nearly straight without any bending, those with a few MeV's could come from the backside of the earth. In this the computations of Rao and McCracken in the middle sixties were to provide the acceptable "cone" for each of the cosmic ray recording station. The acceptance cone depends not only on the location of the station but also to the range of primary energies to which the recording instrument is sensitive.

5.5.4. Cosmic rays produced isotopes for the study of atmospheric circulation

The second major area of work in India was the use of cosmic ray-produced isotopes for studying large scale circulation in the atmosphere (Peters 1962, Lal 1963, Bolin 1964). The possibility of using this arises from the fact that there are several isotopes whose halflives are comparable to time scales involved in atmospheric circulation. Half lives of several radioactive isotopes formed by cosmic rays alongwith their production rates are given in Table 16. Of these S^{35}, Be^{7}, P^{33} and P^{32} were determined

Table 16 *Radioactive isotopes formed by Cosmic Rays* (after Lal, 1963)

Isotope	Halflife	Troposphere	Total atmosphere
H^3	12.5 yr	8.4×10^{-2}	2.5×10^{-1}
*Be^7	53 days	2.7×10^{-2}	8.1×10^{-2}
Be^{10}	2.7×10^{6} yr	3×10^{-2}	9×10^{-2}
C^{14}	5,600 yrs	8×10^{-1}	1.8
Na^{22}	2.6 yr	1.8×10^{-5}	5.6×10^{-5}
Si^{32}	700 yr	5.4×10^{-5}	1.6×10^{-4}
*P^{32}	143 days	2.7×10^{-4}	8.1×10^{-4}
*P^{33}	25 days	2.2×10^{-4}	6.8×10^{-4}
*S^{35}	87 days	4.9×10^{-4}	1.4×10^{-3}
Cl^{36}	3×10^{5} yr		
Cl^{39}	55 min		

in wet precipitation in several stations in India (1956-58) as well as some observations of radioisotopes Be^7 in rain and snow in Chicago and Lafayette during 1955. The choice of these isotopes was determined by the fact that these have lifetimes ranging between 14 and 87 days comparable to atmospheric circulation periods.

The annual deposition rates of Be^7 concentrations in rain zonal belts 10°, 19°, (25 1/2—34°) and 45° latitudes (Peters 1958) gave an average fall-out of 4.5×10^5 atoms/cm² year-consistent with production being mainly below the tropopause (estimated global average production in the troposphere is 7.5×10^5 atoms/cm² year). It confirmed the prevailing belief that the exchange of air between the stratosphere and the troposphere is a slow process, the effective time of which is much longer than the decay time in the stratosphere of the isotopes. The observations were then further used to get some tentative conclusions regarding the average removal period of activity from the troposphere. This period was found to be 35 days by Goel et al (1959) from 11 samples measured at Bombay during monsoon of 1957, and 45 days by Lal et al (1959) from 19 rain samples collected at Bombay. The conclusion was that the removal period is $T_r = 40 \pm 5$ days. These results were obtained from the measurements of Be^7 and P^{33} activities in rain water and an example, after Lal et al (1959) is given in Figure 46. In this the measured ratio of Be^7/P^{32} corresponding to irradiation period larger than t days is plotted against days.

5.5.5 Low Energy Cosmic Ray Events—A New Technique

The IGY saw the emergence of a new technique for the detection of low energy cosmic rays associated with solar flares. This came as yet another application of the cosmic radio noise technique introduced by Mitra and Shain before the IGY (see sec 5.2.2) with modifications introduced by Little and Leinbach (1958). The 'riometer', as the equipment was called, was able to detect vertically incident protons in the energy range 5-50 MeV through excess absorption produced in the ionospheric D region from ionization by these incident protons. Calculations showed that the sensitivity of detection is rather high for 30 MHz, vertical absorption and proton flux are related by: $J\ (> 20\text{Mev}) = 60A^2$, where A is the absorption in db, and J is the 2π omnidirectional proton flux in $cm^{-2}\ s^{-1}$. If the lower limit is set by an absorption of 0.3 db, then the lower limit of detection of proton flux is about 6 $cm^{-2}\ s^{-1}$ (or about 1 $cm^{-2}\ s^{-1}\ ster^{-1}$ in terms of directional flux). The upper limit is imposed by thermodynamic considerations rather than by equipment sensitivity. The ionosphere emits thermal radiation in direct proportion to its power to absorb. The temperature of

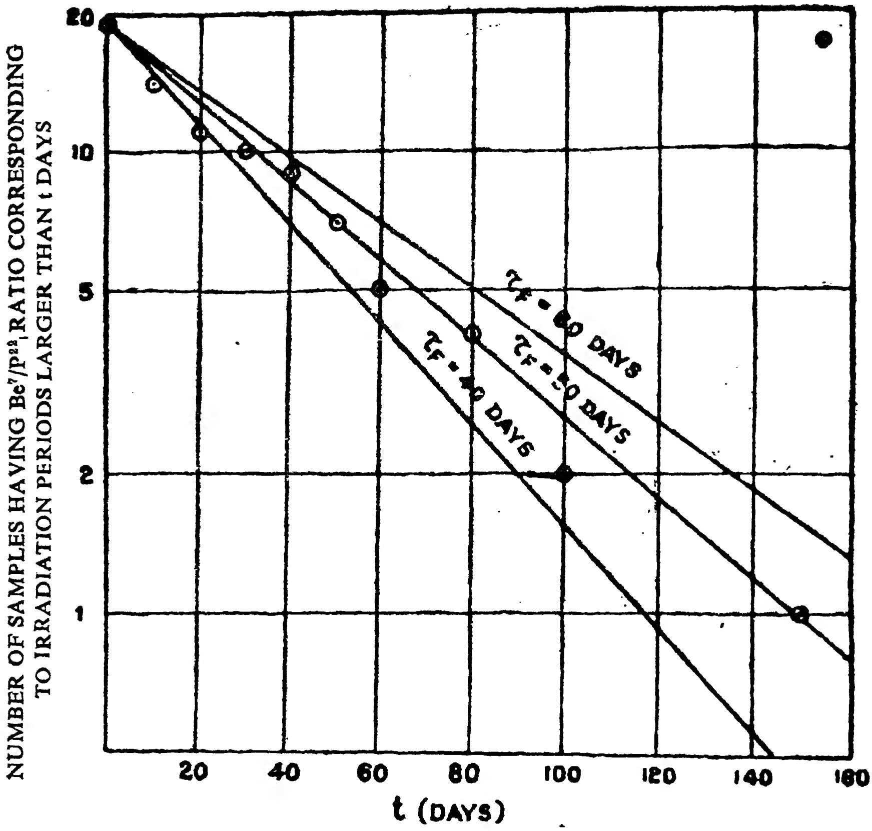

Figure 46. The observed fraction of samples having Be^7/p^{32} ratios greater than that corresponding to an irradiation period, t, days in the trosophere, is plotted. The solid lines show the expected behaviour for three values 30, 40 and 50 days for τ_F the average removal period of activity from the trosophere (after Lal, 1959).

the electrons in the lower ionosphere is of the order of 200 K. When absorption reduces the apparent cosmic noise temperature to 200 K, the riometer begins to measure the noise from the ionosphere itself. Ionospheric thermal radiation begins to be appreciable at 10 db and makes the absorption virtually immeasurable much above 20 db. The limit set by these considerations is a proton flux of about 2.4×10^4 cm^{-2} s^{-1} (directional flux of $4 \times 10^3 cm^{-2}$ s^{-1} $ster^{-1}$). Thus, as a detector of solar protons, the riometer has an approximate dynamic range of 1 to 4000 protons cm^{-2} s^{-1} $ster^{-1}$ for

E > 20 MeV. These values refer to daytime conditions. At night the absence of solar photochemical effects make the lower ionosphere much less sensitive and the primary response is greatly reduced, and is due to protons of considerably lower energies apparently between 3-10 MeV.

Since absorption is maximum at that level where the collision frequency equals the angular frequency of the riometer, for the 27.6 MHz riometer (used in Alaska for detection of flare cosmic ray events), this height was about 50 km. Thus, the equipment, was most sensitive to protons whose penetration depth was about 50 km. That the solar flare cosmic rays consisted largely of protons was already indicated by the balloon observations of Anderson during the flare event of August 22, 1958 (Anderson, 1958).

The events were termed PCAs (Polar Cap Absorption events). Between May 1957 to July 1959, 24 such events were observed by riometers as against 5 occasions in the history of cosmic ray work (till that date) of ground level recording of flare-associated cosmic ray events. The outstanding flare events listed in sec 5.3 (Table 11) include some of the largest cosmic ray events recorded.

There was evidence that solar cosmic rays originating on the western half of the solar disc could reach the earth more easily than those from the eastern half. This was interpreted on the basis of an outward extension of the solar magnetic field by low velocity charged particles travelling radially outward from the sun, as hypothesised by Parker (1958).

5.6 The Earth and Oceans

In these areas the IGY discoveries were not as spectacular as in the areas of atmospheric environment and in sun-earth interactions. There were, nevertheless, important advances: determination of the true form and size of the earth, accurate information on tidal "breathing" and earthquake waves, a mapping of glacier movements (and through these an understanding, of the changing climate); charting of deep sea currents and discovery of a great submarine river (100-800 ft. below surface by the Scripps Institute and the US Fish and Wildlife Service) flowing for more than 3500 miles near the equator in the Pacific about 250 miles wide. In many of these the Indian contributions were, as were indeed planned, part of the total global input information and not individually specifically significant. There were, however, several contributions of special significance; these included, amongst others, the finding relating microseisms with depressions and cyclonic storms (with certain limitations), the detailed study of Himalayan glaciers, atmospheric and ocean circulation using

tracers, the increasing trend of sealevel in the Bay of Bengal and Arabian sea.

5.6.1. *Microseisms and Storms*

The Indian work took advantage of frequent occurrences of cyclonic storms in the Bay of Bengal and the Indian Ocean and concentrated on determining the role of such storms in the generation and propagation of microseisms. The possibility of storms as a source of a special class of microseisms ranging in periods from 2-10 sec was first pointed out by Banerjee (1930) using observations taken with a Milne-Shaw seismograph at the Colaba Observatory during the monsoon period and during passage of cyclonic storms over the Indian Ocean. The intensity and form of microseisms varied with the nature and intensity of the associated weather phenomena, and were believed to be the result of formation of large waves in the storms area causing pressure fluctuations on the sea bed. However, there were in the past several confusing aspects. the fact that microseisms sometimes had their origin at places far away from the storm, the exact manner in which these are transmitted over ranges of intercontinental proportion, lack of appreciable attenuation over land as these propogate through more than thousand kilometers away. The question of using microseismic observations for tracking of storms meant unequivocal determination of direction of approach of microseismic waves. In this aspect several approaches had been developed; the simple technique by Lee of determining the relative amplitudes of the microseismic waves on two horizontal component seismographs, the "tripartite" method of Ramierez in which three senstive seismoqraph are placed at the vortices of a trangle with sides of a few kilometers, and then determining with great accuracy the times of arrival of the wave at the three equipments; the more recent approach of Derbyshire and Iyer in which the vertical component is measured alongwith the two horizontal components on the assumptions that microseisms contain a certain amount of Love waves in addition to Rayleigh waves.

During the IGY 17 depressions and storms were seen in the Bay of Bengal and the Arabian Sea. For 13 of these 17 events, microseismic activities were observed at the four seismic stations; for the remaining four no activity was seen. A summary of the observations is given after Tandon (1961, Figure 47). In this the positions of centers of cyclonic storms and depressions for the observed events during the IGY are given. Depressions are indicated by open circles (when associated with microseisms) and by letter D (when no microseism associated with the depression could be identified). Cyclonic storms are indicated by filled circles and letter C

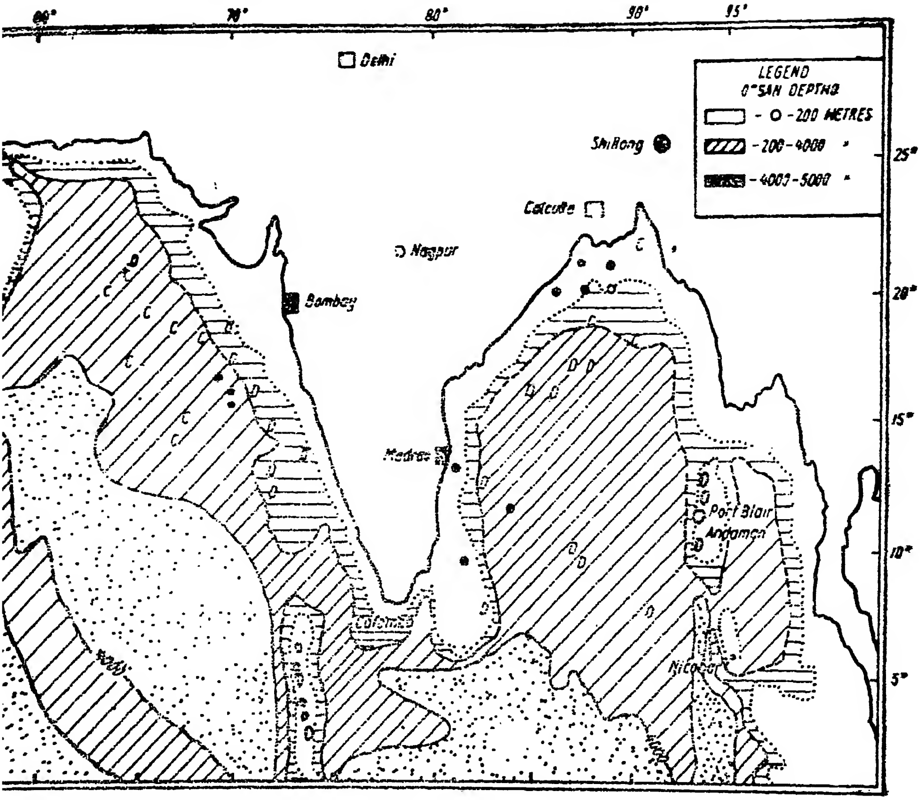

Figure 47. Position centres of cyclonic storms and depression related microseisms (after Tandon, 1961).

respectively for cases when microseisms were detected and when they were not. Since it became clear that the generation of the microseisms is dependent upon depths of the seabeds, contours of seabeds were also given in this diagram in three ranges: 0-200 m, 200-400 m and above 400 m. Inspite of the limited nature of the observations, the diagram clearly shows that good microseismic build-ups at all the Indian stations came where the depressions and cyclonic storm were located in regions of 0-200 m depth, and rarely outside. In the Bay of Bengal certain exceptions sometimes occured, such as the one reported by Tandon (1957) earlier in which good microseismic buildups and amplitudes were recorded at all coastal and inland seismographs for a severe cyclonic storm which had a track right through the central Bay of Bengal from south to north. Curiously enough, the amplitudes recorded did not have a simple relationship with the distance of the storms centre, and amplitudes rose and fell almost simultaneously at all the stations. The periods of microseisms also did not depend upon

the distance, but did depend on the intensity of the storm, showing a rise with increase in amplitudes. Thus the higher the period the more severe was the storm. Periods higher than 4 sec were transmitted relatively more easily through the large seadepths.

The Indian workers also reported a few other types of microseisms. One concerned the appearence of microseisms of very short periods (0-4s), lasting for half to 2-3 hours, remaining practically steady over the entire periods and believed to be associated with the resettlement of underground structures. Another type was associated with the progress of monsoons, seen weeks before the onset of monsoons on the coast of the Bay of Bengal (Chakravarty, 1958).

5.6.2 *Study of Himalayan glaciers*

A number of Himalayan glaciers were revisited. A description of these glaciers, their locations and igformation about retreat of advance of the glaciers, as summarised by Jangpangi (1958), are given in Table 17. The main conclusion was that the glaciers in the Central Himalayas were in the retreating phase during the few decades preceding the IGY. There was some indication of advance in a few of the transveral glaciers like Poting and Arwa valley in the 30's. Jangpangi and his colleagues concluded that these glaciers had a phase of advance between the initial retreat and the final retreat; the latter occurred after the thirties.

5.7 Geomagnetism

The existence of an equatorial electrojet in the immediate vicinity of the dip equator was already known by the time IGY began. The strength of the electrojet current was estimated by the enhancement of the diurnal range in H. McNish showed that this range is abnormally high at Huancayo and Egedae (1947) subsequently found similarly large values for an Indian station Kodaikanal. Much work was done on the location of the electrojet in relation to magnetic and dip equators by a number of authors including works from Indian scientists Pramanik et al (1952-53). The dip latitude θ, it will be recalled, is defined for any station and year by the equation:

$$\tan\theta = \frac{\bar{Z}}{2\bar{H}}$$

where $\bar{Z}$ and $\bar{H}$ are the mean values of the *total* field components Z and H over the year for that station. The coordinate θ corresponds to the co-lati-

Table 17 *Glaciers Visited During IGY*
(From Jangpangi, 1958)

Name	Latitude & Longitude	Altitude	Type of glacier	Period of study	Area/Length breadth	Direction of flow gradient	Velocity	Firm or Nave-line Elevation	Area of accumulation & ablation	Snow elevation	Retreat or Advance	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13
A. PUNJAB												
KANGRA DISTRICT												
GAGLU GLACIER	32°21′ 40″ 32°28′ 10″ and 77°20′ 40″ and 77″26′ 40″	Snouts at 13,026 ft	Valley	August-Sept. 1958	Approximately 20 sq. miles length 8½ miles	SE for 3½ miles then South 760′ per mile	At margin 0.57′ perday at centre 3.14 perday	15,300	19½ sq. miles & 3½ sq. miles	15,300		Ice falls are present with transverse crevassecs
BARA SHIGRI GLACIER	32″16′ : 77″25′	4,700 metres		July-Aug. 1956							Retreat of 100 metres since 1906	
SONPANI GLACIER	32°25′ 77°25′	Snout at 12,650 ft.			9.1 miles long				11 sq. miles & 1½ sq. miles	14,000	Retreat	
B. UTTAR PRADESH												
1. ALMORA DISTRICT												
PINDARI GLACIER	Snout :— 30″15′ : 88°02′		Transverse	20th Aug. to 10th Sept. 58	Length 3 1/4 miles	Southward upto 2½ miles & then to SE					Retreat 3,400 ft. since 1906	Maximum retreat of all glaciers surveyed
KAPHNI GLACIER	Snouts : 30°13′ 20″ 80°03′		Transverse	13th to 23rd Sep. 1958	2 miles in length	Southward	At steep portion 1.41′ & 1.33′ on margins and 1.16′ in At lower level 0.41 on margin & 0.68′ on central region				Retreat	Movement measured in 45 hrs.

(*Contd.*)

Table 17 (*Contd*)

1	2	3	4	5	6	7	8	9	10	11	12	13
MILAM GLACIER	2½ miles NW of Milam			Aug. to Oct. 57	12 miles						Retreated 2,030 ft. since 1906 & 350 ft. since 1939	2nd largest glacier in central Himalayas.
POTING GLACIER	30°12′ 45″ 50°09′ 30″		Transverse	Aug. to Oct. 57			Toward right margin near curvature, is 15″ in 24 hrs.				Retreated 860 ft. since since 1906. Apparently retreat only since the thirties	
SHUNKALPA GLACIER	30°20′ 80°19′ 30″		Transverse fed by two tributary glaciers	Aug. to Oct. 57	Each tributary nearly 7 miles & after confluence 2½miles						Retreating 1,000 ft. since 1906	
					2. TEHRI GARWAL							
GANGOTRI GLACIER	30°50′ 79°04′	12,770 ft.	Longitudinal or valley	18th July to Aug. 1st' '56	18 miles in length	WNW direction					Retreated 700 ft. since 1935	Largest glacier in central Himalayas
GLACIER No. III	30°52′ 20″ 79°20′		Transverse	28th Aug. to 15th Sept. 56		Northward; Gradient; 12					Retreated 650′ since 1932	
ARWA VALLEY											Reduction of thickness of about 25 ft. at snout	
SATOPANTH GLACIER	2,000 ft. SSW of 30°46′ 30″ 19°25′		Longitudinal		8 miles in length	ENE					Retreating	
BHAGIRATH KHARAK GLACIER	30°46′ 30″ 79° 25′		Longitudinal	10th Sept. to 14th Sept. 56	11 miles in length						Retreating	
SIACHEN GLACIER	35°12′ & 35°41′ & 77°11′ & 76°47′	Snout ;— 12,500 ft.	Longitudinal or valley	Aug. & Sep. 58	45 miles in length	SE to SW then to SE ; 100′ in a mile					Retreating	Secular variation

(*Contd.*)

Table 17 (*Contd.*)

1	2	3	4	5	6	7	8	9	10	11	12	13
MAMOSTONG GLACIER	35°00′ 35°09′ & 77°32′ 77°35′	Snout :— 14,900 ft.	Longitudinal or valley	Aug. Sept. 1958	10 miles in length	Due south; 300′ per mile					Almost stable since 1935	Secular variation
CHONG KUMDAN GLACIER	35°10′ 35°12′ & 77°38′ 77°43′	Snout ends at 15,500 ft.	Transverse	Aug. Sept. 1958	10 to 12 miles in length width of snout 4,000 ft.; glacier width about 2 miles	Easterly direction					Advancing	Ice pinnacles have developed. Glacier is a periodical type;, forms a natura dam for Syok valley (periodic curve of 51 years—advancing, blocking the main riverl bursting & retreating)' 100′ left for damming the Syok valley.
KICHIK KUMDAN GLACIER	35°07′ & 35°09′ & 77°40′ & 77°43′	Snout at 15,230 ft.	Transverse	Aug. & Sept. 58	7 miles in length	Easternly direction; 500′ per mile; ending in Syok valley					Retreating 4,000 since 1946	Ice pinnacles prominent; periodicity of 45 years
AKTASH GLACIER	35°06′ 35°07′ 77°42′ 77°44′	Snout at 15,000 ft.	Transverse	Aug. Sept. 1958	5 miles in length	Easterly					Advancing	Periodicity of 45 years; by 1960 it would be in Snyok valley.
2. SRI NAGAR												
MACHOI GLACIER	341°6′ 75°32′	12,300 ft.	Transverse	Aug. 57	2 miles long; Area; 2 sq. miles	Northerly direction gradient is 37%					Retreated about 15,000 fit. since 1906	

tude for a simple dipole field giving rise to the values of Z and H that are observed at the station. Since the inclination I at station is defined by :

$$\tan I = \overline{Z}/\overline{H}$$

θ is related to I by

$$\tan \theta = 1/2 \tan I$$

The stations operated during the IGY in the vicinity of the geomagnetic and dip equators are listed in the table 18 along with their geomagnetic and dip latitudes as also the ranges of Sq(X) in gammas for the three seasons: J months, E months and D months (Price, 1964). The great enhancement of Sq(X) as one progresses towards the dip equator is evident. An example is given in Figure 48. Several important points can be noticed from Table 18.

Firstly we notice that there is an important seasonal effect in the electrojet intensity. The Sq(X) range was the largest for the E months. The ranges for the J and D months were not greatly different except for Jarvis Island; this suggests there is no important seasonal shift of the jet. Jet effect extends as far as as Chidambaram for the D months.

Secondly the jet intensity was greater in South America than elsewhere; and almost twice as much as in the Indian zone. The greatest ranges for Sq(X) occurred for all three seasons at Huancayo. The next greatest range during the J and E months occurred at Korar in Africa. One should note that in 1958 Korar was exactly on the dip equator where as Huancayo was 1°N of it.

We would like to discuss the longitudinal effect a little more in detail since there was a considerable amount of original work from African and Indian scientists in this area (Onwumechilli 1959, Rastogi 1962). The works of Ogbuchi and Onwumechilli (1963) during the IGY using 10 stations across the magnetic dip equator in Nigeria showed that the axis of the equatorial electrojet was located on the dip equator (10.2° N latitude in Nigeria). One would then couclude that in the American zone the maximum magnitude of Sq(X) range is even larger than at Huancayo. Onwumechilli found a width of 440 $\pm$ 20 km for the width of the electrojet in the African zone; this width appeared to decrease with solar activity. On the model of a uniform current at 110 km, the current intensity was estimated to be 116 amp km^{-1}. Rastogi used the data from the American, African and the Indian zones. The data for the American zone were from the surveys made in 1949 and 1957 with the Huancayo as reference station. The two surveys which gave essentially similar results, showed that the maximum range in H was found at Chincha (latitude 13.4°S); the dip equator in this zone passed through the latitude 13.3°S

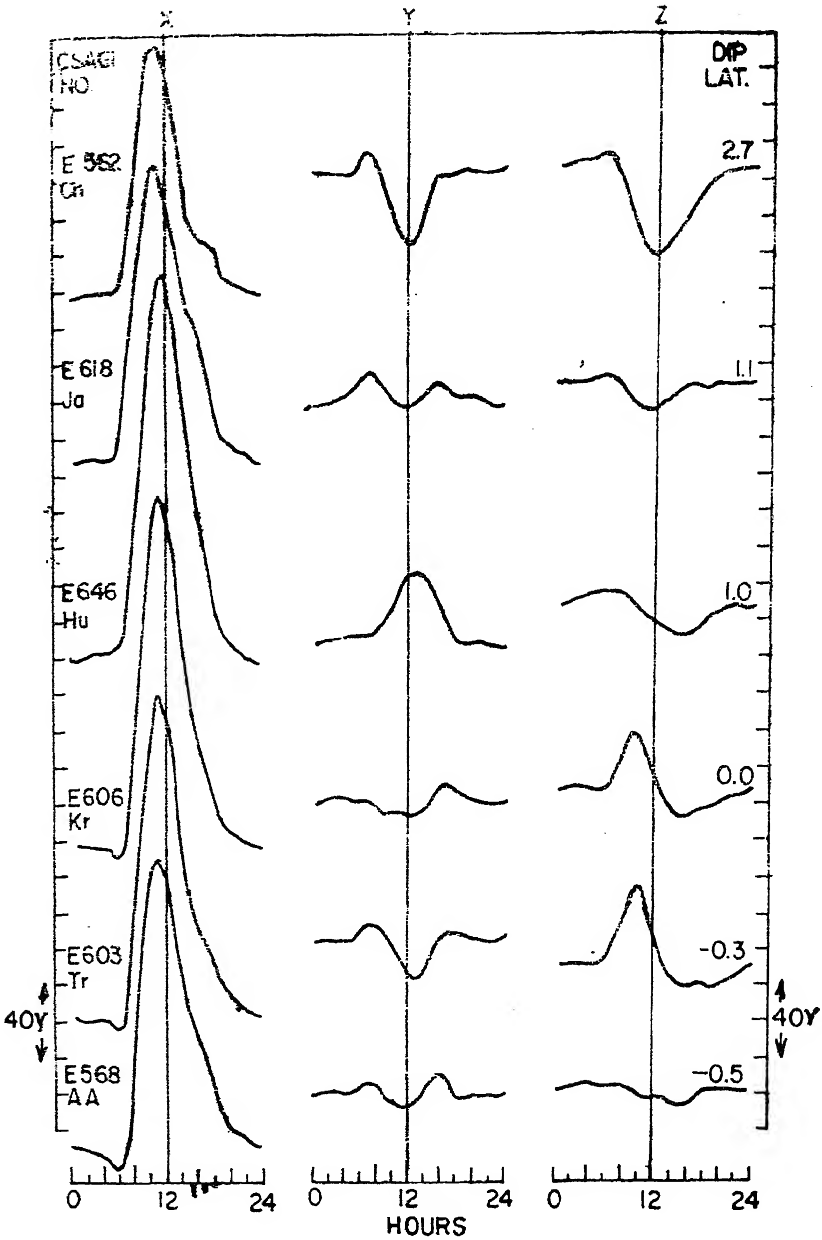

Figure 48. Average variation of Sq(X) at equatorial stations during quiet days of March, April, September and October, 1958.

and the geomagnetic equator through 11.4°S. It was, therefore, clear that the maximum in the range occurred closer to the dip than to the geomagnetic equator. The range in H over the magnetic equator was about 2.3 times that outside the electrojet zone.

For the African zone, the data were for the period November 1956 to January 1957 with the reference observatory at Ibadan. In this zone, the maximum of the electrojet was found to be about *0.5°S of the magnetic equator* and the range over the magnetic equator was about 1.9 times that outside the electrojet zone. The width of the electroject was very narrow about ± 3° latitude.

For the Indian zone, the reference observatory was taken as Kodaikanal. The Indian observations also indicated that the electroject maximum occurs on the dip equator and not on the geomagnetic equator. This was clearly shown to be the case by Rastogi by using the station doublets Kodaikanal and Trivandrum. Kodaikanal was closer to the geomagnetic equator than Trivandrum, but Trivandrum was only a few miles away from the dip equator. Rastogi showed that the quiet day values of the ranges H were almost always larger at Trivandrum than at Kodaikanal. This is shown in Figure 48. The ratio of the range over the magnetic equator to that outside the electroject was low being only about 1°S in South India. The electrojet intensity was, therefore, largest in the American zone and the lowest in the Indian zone. The larger values at Huancayo in relation to Trivandrum are shown in Figure 49 after Rastogi, which gives the average quiet day variation in H in different seasons.

The question of direct measurement of the current systems causing the geomagnetic field by rocket-borne magnetometers was taken up seriously during the IGY. Some measurements were already available, carried out by Maple et al (1950) and others, using fluxgate type total field magnetometers and in one flight made near the magnetic equator, an intense ribbon of current was observed. However, the rocket had not completely penetrated the electrojet current, and the fluxgate magnetometer was not found to be entirely satisfactory. A small rugged magnetometer was developed for the IGY by the State University of Iowa, and a small rocket-balloon combination (rockoon) was used for launching. Equatorial launchings were arranged on board USS Glacier, a Navy icebreaker, which was to go from Boston to the Antarctic. The location of the launchings were chosen near Line Islands in the mid-Pacific where three ground magnetic observatories had been set up for IGY by the Scripps Institute of Oceanography (Palmyra Island, Fanning Is, Christmas Is). The *ground path* available from these observatories helped in interpretation of the data as well as defining the degree of magnetic disturbance at the time of the observations. Six flights were launched during the period October 14-19 in 1957.

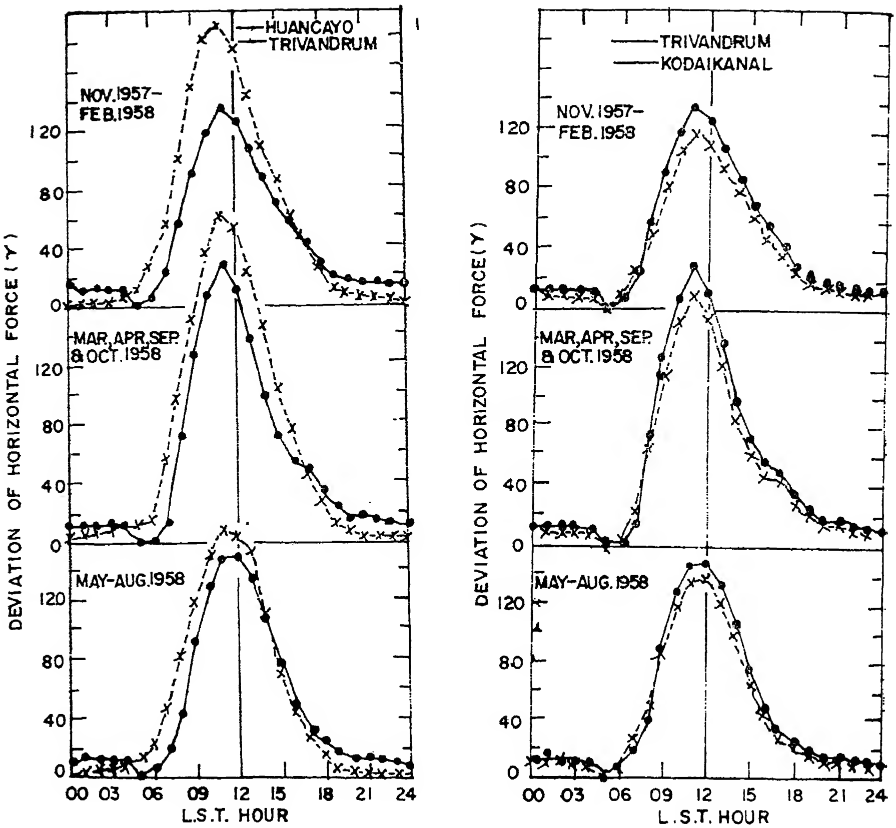

Figure 49. (a) the diurnal variation of H at Huancayo and Trivandrum during different seasons of IGY and (b) the diurnal variation of H at Trivandrum and Kodaikanal *during different seasons (after Rastogi, 1963).*

For three of these flights, there was no departure from the inverse cube decrease of the magnetic field and it was assumed that these flights did not penetrate the current layers. For the other three flights (Flight 83, 86 and 87) departures were noticed. Flight 83 allowed measurements upto 125 km. showed an abrupt change in slope at 104 km and resumed original slope at 108 km, indicating existence of a very thin current sheet. Flight 86 was launched just 30 miles northwest of the Jarvis Observatory (the observatory recording the largest diurnal range). An increase in slope was observed at 97 km and the resumption of the normal slope at 110 km. A curious feature was a further departure starting around 117 km, indicating existence of two distinct layers of electric current. The departure from the inverse cube law at the peak of the flight was 138 ± 10γ. The departure

amplitudes were not the same in all cases; for example in flight No. 87, the departure was considerably higher 300 ± 20γ. These departures were converted into approximate values of current densities assuming the electrojet to be infinite in lateral extent. The measured current densities agreed with calculated ionospheric conductivities. For locations near the magnetic equator the special conductivity introduced by Martin, Cowling, Massey and others provided an explanation for increased conductivity near the magnetic equator. J_3 refers to currents flowing parallel to electric fields and transverse to the magnetic field in the special case where Hall current is prevented from flowing. Near the magnetic equator the magnetic field is horizontal and the Hall current does not have a horizontal component. A polarisation is built up between the top and bottom surfaces of a conducting layer; this prevents further flow of Hall current and cancels the retarding effect of the magnetic field. The resulting conductivity is very high. However, the conductivity calculations provided only a single narrow maximum near 100 km and the existence of the two layers of current were difficult to explain. Cahill (1959) suggested that a possible explanation may be the presence of intense Sporadic E near the magnetic equator at the time of the flights.

There were unfortunately no such measurements over the Indian subcontinent during the IGY. However, later measurements were undertaken from the geomagnetic equatorial station of Thumba several years after the IGY when this range became operational. These experiments were done by Maynard and Cahill (1965) and later by Sastry (1970). The Indian zone measurements indicated peak current density around 107±2 km with the current amplitude being of the order of 9 amp. km^{-2} around noon time flowing from west to east. Half width of the jet current was around 10 km in the vertical direction. It is important to note that the current amplitude in the Indian zone was half as intense as that in the American zone. A second (weak) layer was also observed by Maynard and Cahill (1965) between 140-145 km on January 27 and 29, 1964, the latter day being magnetically slightly disturbed. Sastry flew a proton precision magnetometer just after a proton flare on July 7, 1966 (Sastry, 1973) and also noted the existence of a second current layer near 130-140 km. He concluded that appearance and disappearance of this second layer is one of the causes of large day-to-day variability of diurnal variation observed on the ground.

One of the most interesting contributions from Indian scientists was the presentation of a new theory of earth's magnetism (Chatterjee, 1961). Chatterjee showed that due to the non-linear properties of the mantle earth, the solar particle stream causes a small unidirectional current to flow in

the mantle and the liquid core of the earth. This unidirectional current goes on increasing through successive disturbances. The final value of the current is sufficiently large to explain the observed magnetic field of the earth. The crust also becomes permanently magnetised to saturation. Chatterjee further showed that the circular variation and the reverse rate magnetism can be explained by this theory.

Table 18 *Sq (X) ranges in gammas for stations near the dip equator (After Price and Stone, (1964)*

Station	Geomagn. latitude	dip latitude	J months	E months	D months
Alibag	12.9°	9.5°	80	77	61
Muntinlupa	3.1°	7.2°	88	94	79
Chidambaram	1.8°	2.7°	111	137	91
Jarvis Island	−0.6°	1.1°	116	164	170
Huaneays	−0.6°	1.0°	164	214	177
Koror	−3.2°	0.0°	161	198	160
Trivandrum	−1.2°	−0.3°	145	188	120
Addis Ababa	5.3°	−0.5°	136	177	128
Bangui	5.0°	−7.0°	81	95	77

6. Concluding Remarks

The groups formed during the IGY in the different areas of geophysics—the earth, oceans, the atmosphere and the sun—and the interactions that evolved amongst the Indian scientists in these areas provided the foundation for future programmes.

The next international programme that came was that of the International Quiet Sun Year (IQSY). The IQSY was a follow-up of the IGY, and was planned to coincide with the period when the solar activity was expected to be at its next minimum after the very high activity during the IGY. The IQSY started on Jan. 1, 1964 and ended on December 31, 1965. Building on the base formed during the IGY India became a major partner of this international programme in which some 40 countries participated. The programmes were undertaken in all the IQSY disciplines: Meteorology, Ionosphere, Geomagnetism, Cosmic Rays, Aeronomy and Solar Activity. The planning and implementation of the programme was

done by an 11-member committee with K.R. Ramanathan as Chairman and A.P. Mitra as Secretary, with the Secretariat located, as during the IGY, at the NPL, New Delhi. Solid earth and ocean areas were not undertaken since the interaction of solar radiation with these was not evident. The stations operated during the IGY were, in most cases, continued and the stations near the geomagnetic equator strengthened, since the Trivandrum station was still not well-equipped. The NPL installed a Riometer inside the meteorological observatory at Trivandrum for the measurement of cosmic radio noise, and the manual ionospheric recorder was replaced by an automatic one. One of the most important accomplishments was the installation, in time for India's participation in the IQSY, of an equatorial Rocket Launching Facility at Thumba, near Trivandrum, under the supervision of the Indian National Committee for Space Research, and a series of high-altitude balloon flights, designated IQSY—EQUEX Project, organized by TIFR at Hyderabad jointly with some U.S. laboratories. Other experimental techniques added were : reception of satellite radio beacon transmissions at New Delhi, Ahmedabad, Hyderabad and Kodaikanal and the installation of a radio dopplometer at Haringhata (near Calcutta) by NPL jointly with Calcutta University. The meteorological programme had an added value in view of the Indian Ocean Expedition then underway in which India played an important role. In the area of magnetism, new additions were : an earth current recording station at Hyderabad (NGRI) and two micropulsation observatories, one at Ahmedabad (PRL) and another near the magnetic equator. The IQSY network consisted of 50 stations at nearly 20 places spread all over India, from Srinagar in north (34°4'N) to Trivandrum in south (08°29'N) and Bombay (72°50'E) in west to Gauhati (91°53'E) and Port Blair (92°56'E) in the East. As during the IGY, the major burden of the programme was shouldered by young scientists, many in their twenties. The rocket flights conducted during the IQSY from Thumba are given in Table 19. Although there was a considerable amount of space-related activities during the IGY, space age in India really began during the IQSY.

Following the IQSY there were several international programmes, such as the Global Atmospheric Research Programme (GARP), the International Magnetospheric Study (IMS), the Solar Maximum Year (SMY)—none of these as comprehensive as that of the IGY, but were targeted at specific aspects of the earth-space environment. Indian participation in these was also limited, except in GARP.

More recently, a new programme has been launched in which India's participation is massive. This is the MAP—the Middle Atmosphere Programme—that started on Jan. 1, 1982 and will end on Dec. 31, 1985 (a continuation of this programme to allow for scientific studies of the data collect-

ed and initiation of new major experimental facilities, such as MST Radar, and use of satellites specifically designed for the middle atmosphere, has recently been accepted by SCOSTEP). In this programme the thrust is on a relatively narrow part of the atmosphere, from about 10 km to 90 km, stretching between the tropopause and the mesopause (Figure 50). This is one of the most difficult regions to study, much of it beyond the reaches of high altitudes balloons and below the reaches of satellites for *in-situ* measurements, and also, since there are few or no electrons below 50 km, not responsive to radio techniques for most of the region. Attention has, in recent years, been dramatically focussed to this region with the increasing realization of the frail nature of the stratosphere (subject to catastrophic changes through human influences) and its possible role in providing the coupling between the variable solar UV flux and the lower atmosphere. The single most important constituent is ozone, providing both a screen for biologically hazardous UV-B radiation, and, through "greenhouse" action a modulation of the heat budget. But ozone variations are linked with variations in a number of other consituents, much of which emanating from the surface (methane, from biomass burning and from paddy fields; carbon dioxide from fossil fuel and biomass burning; NO_x from forest fires, etc), and with a multiplicity of sources, natural and anthropogenic *natural*: solar protons, volcanic eruptions, lightning discharges; *anthropagenic*: biomass and fossil fuel burning, aerosol sprays, spacecrafts effluents, nitrogenous fertilizers). From the massive research activites mounted in the seventies on the ozone problem, it became clear that many of these minor species add to the greenhouse effect of CO_2 (by a factor as high as 80%) and are, therefore, climatically important. Since much of the natural source comes from the equatorial regions (paddy fields, biomass burning) the importance of such studies for the equatorial areas like India was obvious.

The MAP identified the following as its major objectives:

* What are the possibilities of damage to earth's middle atmosphere from man's activity?

  e.g. Ozone problem

* what role does middle atmosphere play in determining climate and climatic changes?

* What are the processes by which the sun, acting through the middle atmosphere, may be able to affect weather?

  e.g. Sun-weather Relationship.

Indian interest in this programme arises from several excellent facilities that now exist and the interest regarding the role of the middle

Table 19 *Rocket Experiments from Thumba during IQSY*

Nov. 21, 1963 1825	P.D. Bhavsar (PRL) —CNES	Sodium Cloud Upper atmospheric winds	170–100
Jan. 8, 1964 1845	P.D. Bhavsar (PRL) —CNES	Sodium Cloud Upper atmospheric winds	100–185
Jan. 12, 1964 0556	P.D. Bhavsar (PRL) —CNES	Sodium Cloud Upper atmospheric winds	100–170
Jan. 25, 1964 1044	N.C. Maynard (USA) L H. Cahill (USA)	Proton magnetometer DC Probe	164–
Jan. 27, 1964 1000	N.C. Maynard (USA) L.H. Cahill (USA)	Proton Magnetometer DC Probe	165–
Jan 29, 1964 1530	N.C. Maynard (USA) L.H. Cahill (USA)	Proton Magnetometer DC Probe	167–
Jan 31, 1964 1900	N.C. Maynard (USA) L.H. Cahill (USA)	Proton Magnetometer DC Probe	168–
Nov. 6, 1964 0538	P.D. Bhavsar (PRL) —CNES	Sodium Cloud Upper atmospheric winds	100–170
Nov. 9, 1964 1825	P.D. Bhavsar (PRL) —CNES (France)	Sodium Cloud Upper atmospheric winds	100–170
Nov. 10, 1964 0535	P.D. Bhavsar (PRL) —CNES (France)	Sodium Cloud Upper atmospheric winds	100–170

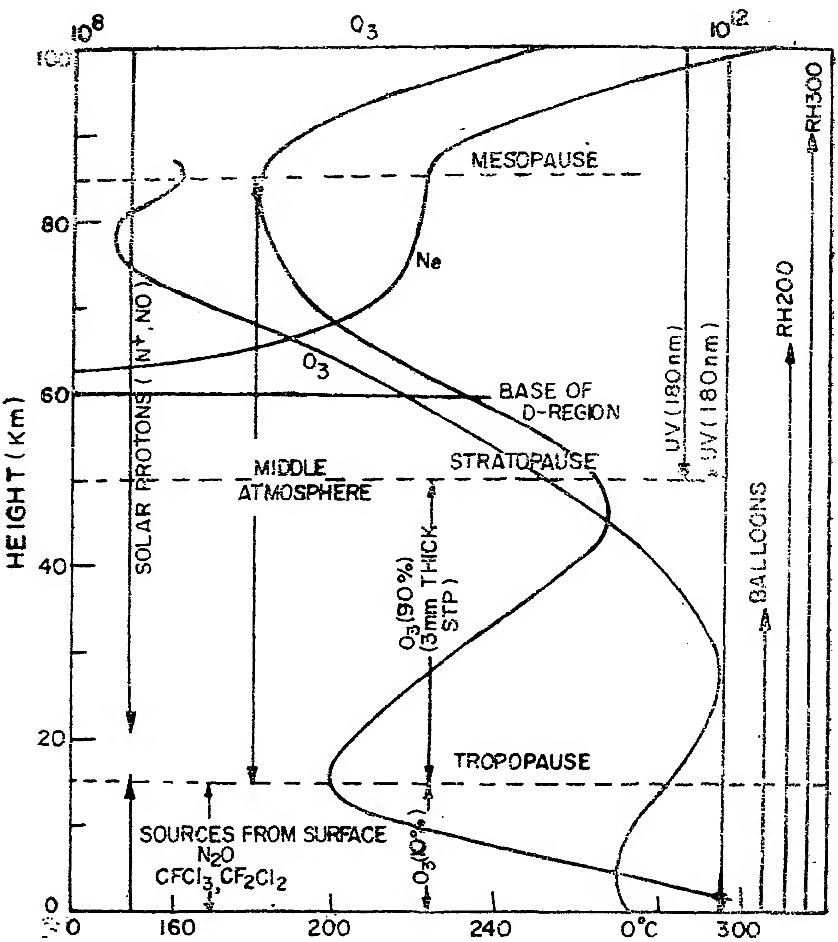

Figure 50. The middle atmosphere stretching from tropopause to mesopause.

atmosphere in monsoon cirulation and atmospheric chemistry. Some special aspects are outlined below:

* Availability of 3 rocket ranges: Thumba (9°N), SHAR (14°N) and Balasore (21°N).
* Availability of a national balloon launching facility at Hyderabad.
* A dense network of radiosonde stations operated by the IMD and its continuing operation of key experiments: (a) Ozone measurements with Dobson spectrophotometer and balloon-borne sensors (b) atmospheric turbidity measurements in 10 stations.

* Development of new facilities:

  Meteor Radar at Thumba

  Lidar at Thumba

  Laser heterodyning facilities at Delhi
* Role of middle atmospheric dynamics and chemistry in monsoon circulation
* Special aspects of atmospheric chemistry

  Large production of CH_4 from paddy field

  Largescale deforestation (CH_4, CO_2, CO, NO_X)

  High level of tropopause (16-18 km) in contrast with low level in mid and high latitudes ($\sim$8 km)
* Relatively clean stratospheric ionization (only known source leading to variation being aerosol concentrations and size distributions)
* Equatorial to midlatitude conditions obtaining in the same country and occuring around the *same longitude zone* ($\sim$75°E)
* Region of low ozone content, with more severe biological consequences in case of depletion.
* An ideal location for testing the role of lightning discharges in atmospheric chemistry and in the ozone problem
* Side-by-side existence of "slash-and-burn" agricultural regions with "sacred" forests: an ideal opportunity to test the role of CH_4 in O_3 production and destruction
* High tropospheric water vapour content in certatin seasons, producing much larger inputs of the scavenger radical OH.

The Indian programme that has been organized involves the participation of some 200 scientists (at least 50 which are young scientists in the thirties and twenties). The young scientists whose initiation in earth space environment programme occurred during the IGY are now leaders of the IMAP. Direct involvement of seven agencies (DOS, DST, CSIR, UGC, DOE, DOEn, DTCA), several national Research Institutions and 11 universities has produced a management structure that looks promising. A major fallout is the undertaking of an MST Radar as a national facility: the radar design has been completed, location tentatively decided, and frequency clearance provisionally obtained. The Radar is expected to operate in ST mode (stratosphere-troposphere mode) by December 1986 and MST mode by December 1988.

The different facilities currently in operation are shown in Figure 51; radiosonde distributions including specially selected stations for high-altitude observations and ozone stations operated by the IMD are given in Figure 52. In the context of the IGY, one may note the important contributions in this programme by groups set up at the time of the IGY: at Delhi (NPL), at Ahmedabad (PRL), at Calcutta (Calcutta University), at Poona (Poona University), at Waltair (Andhra University), at Bombay (IIG) and at many stations by IMD. New groups have grown at Trivandrum (VSSC, Kerala University), Poona (IITM) and other places, but some of the old groups have unfortunately vanished. One disturbing feature is that while during the IGY, the contributions from University scientists and scientists from national institutions were comparable, the University component is now less and limited to traditional techniques with a few exceptions.

Over the years from the period of the IGY to now, our concept about atmospheric science has changed drastically. We now view the atmospheric environment as one entity. From the ground to the boundary of the magnetosphere the many classically recognized regions-the troposphere, the stratosphere, the mesosphere, the ionosphere, the magnetosphere-have now merged, and coupling between various levels has been recognized. Another major change is the realisation of the very important role that atmospheric chemistry plays in many areas of atmospheric and ionospheric sciences, at essentially all levels of the atmosphere: in the troposphere (of climatic interest), in the stratosphere (the ozone problem), in the ionosphere (inadvertent or deliberate modification by injection of chemical species from spacecrafts), and near the ground (biogeochemical cycles). However, the boundaries have been erased only with difficulty, and in many countries, as in ours, only incompletely. Climatic modelling, regional or global, continues to ignore the role of stratospheric-tropospheric coupling, and of critical minor species such as ozone, and methane and of the varying concentrations of aerosols, on a shortterm and longterm (following volcanic eruptions such as the recent eruption in El Chichon) basis. The subject of tropospheric chemistry hardly existed a decade ago; its role in predicting diffusion of local atmospheric pollution and in global haze, although critical, is hardly mentioned. Agricultural and animal scientists in India have not yet considered the question of continuous increase of methane concentrations in the atmosphere, nor of the linkage of biomass burning with atmospheric changes.

However, the most important weakness—not merely in India, but globally—has been a complete neglect of biosphere-geosphere connection. Ecological and biological processes were ignored during the IGY, and in

IMAP FACILITIES AND INSTITUTIONS

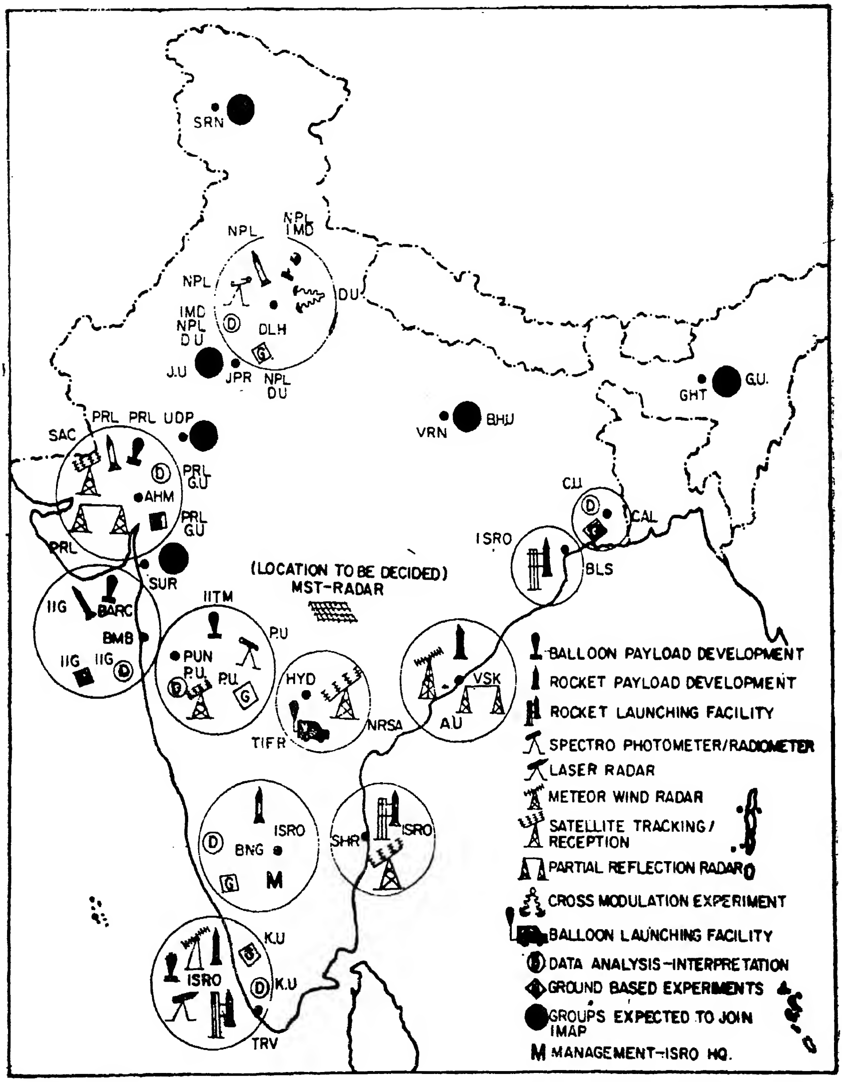

Figure 51. IMAP Facilities and Institutions currently in operation in India. (modified from a diagram prepared by IMAP Headquarters)

IMAP-IMD OBSERVATIONS

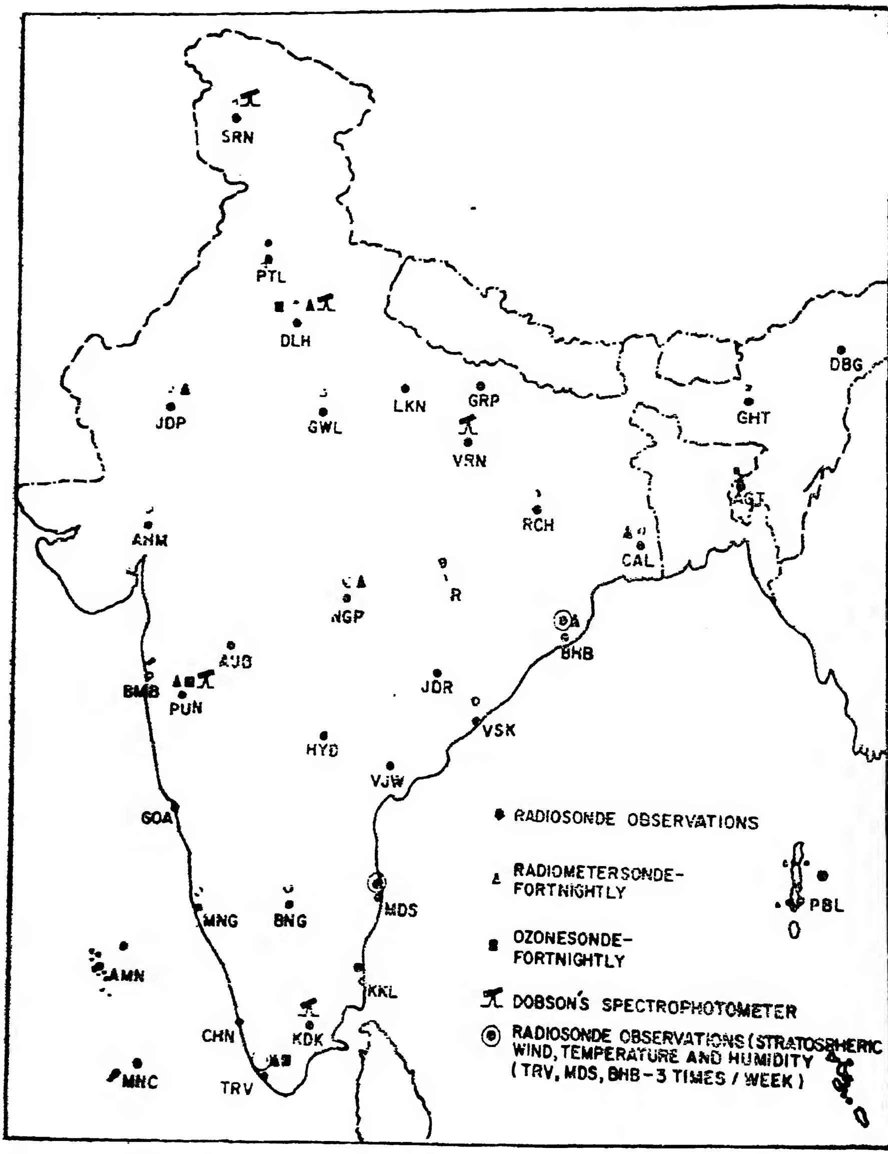

Figure 52. IMAP-IMD stations operating Radiosonde, ozonesonde and other facilities in India. (courtesy : IMD)

most of the subsequent programmes like GARP, WCRP (Global Climatic Research Programme) and even currently in the MAP. This connection has been increasingly evident in recent years: an example is the injection of atmospheric constituents from biological processes at the ground (summarised in Figure 53). The USA have proposed the undertaking of a long term multidisciplinary programme called the "International Geosphere-Biosphere Programme (IGBP)" and the ICSU has considered the entire question of *"Global Change"* in its last Assembly through specially arranged discussions. Global habitability or global change works through interactions between the sun, atmosphere, oceans, lithosphere and biosphere, only a few of which have come under any international programmes. Future programmes in earth-space environment, of which the IGY was a major milestone, will have to concentrate on such interactions.

The geosphere-biosphere linkages and a few of the major international programmes that connect some of these are shown in Figure 54. The sun-atmosphere connection is, or has been, covered by the several international programmes: MAP is one of them. Atmosphere-ocean connections have been examined through programmes such as WCRP, GARP, WWW, WOCE, TOGA, IHP. The Biosphere itself has been or is being studied very extentsively through GEMS (Global Environment Monitoring System, a part of the United Nations Environment Programme), through MAB (Man and Biosphere, a programme of the UNESCO), through the programme of the Decade of Tropics and the ABC (Analysing Biospheric Change). For the lithosphere there are two international programmes: the IGCP (International Geological Coordination Programme and the ILP (International Lithosphere Programme). However, there are no programmes connecting the Lithosphere and the Biosphere or the Biosphere and the Sun. The Biospbere-Atmosphere connection study has only recently been initiated through examination of biogeochemical cycle, in which work in India is still on a very low key, or through studies such as "Nuclear Winter". The ICSU "Global change" programme has indicated a number of areas, some of which of interest to India. are listed below.

Objectives of Biosphere-Geosphere Programmes

Examine (energy-wise) "strong interactions between biosphere, atmosphere, hydrosphere and lithosphere, especially as manifested in major geo-biochemical cycles"

Incorporate study of "slow" global transitions that have taken place in the past

Study of the "weak" interactions mediated by solar variability through sun-earth space linkage

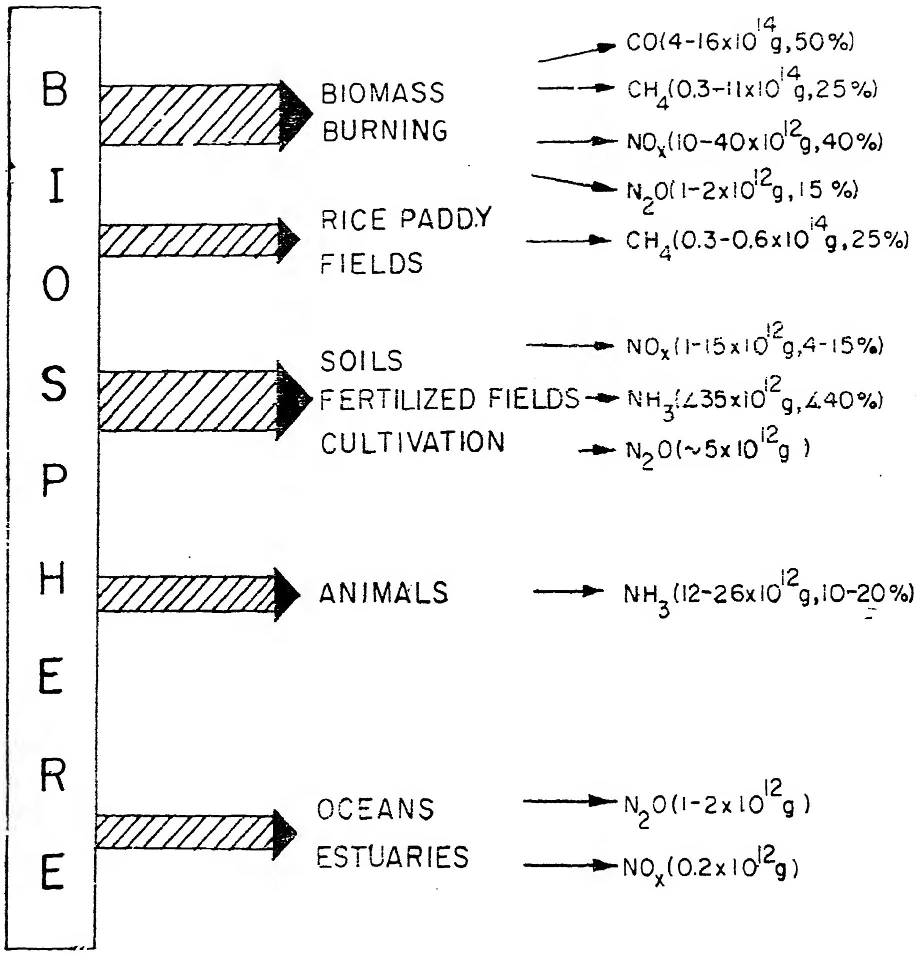

Figure 53. Diagram showing the injection of atmospheric constituents from biological processes, (prepared from values given by Crutzen, 1982)

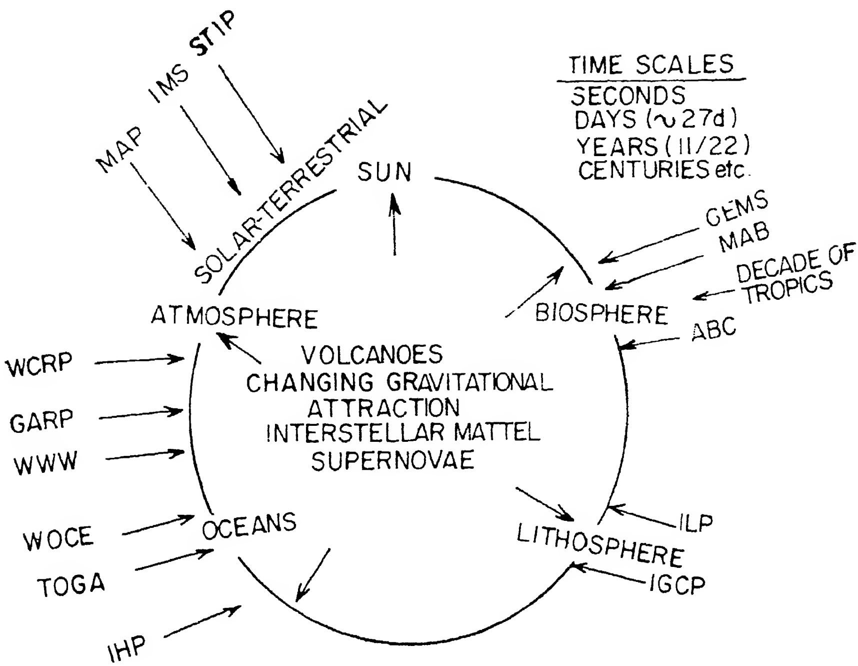

Figure 54. The Biosophere—Geosphere linkage and a few international programmes that connect these linkages.

Prepare data bank of interrelated parameters in coherent, continuous, intercomparable form

Strategies

Must address a number of *well-defined* scientific problems, but sufficiently important, *multifaceted* and *global* in nature

Must offer meaningful opportunities for participation to scientists of all nations including developing countries, as during the IGY

Must incorporate currently operating international programmes

Cross biosphere-geosphere "barrier"

Future efforts in India may well be directed to some or all of these areas. The scientific manpower requirement will no longer be able to depend upon the IGY heritage, nor is it desirable to do so, since one now wants to cross the boundaries between physical and biological sciences. This requires different kind of scientists and a different approach to science. India is fortunate to have a strong interaction between physical and biological scientists. It would be important to take advantage of this.

A. References appearing in the Text

Allcock G.M., (1959), J. Atmos. Terres. Phys., **14**, 185

Anantasayanam M.R. and Narasimha R., (1979), Proposed Standard for Critical Atmospheric Distribution in India, Report 79, FMS, Dept. of Aeronautical Engineering, Indian Institute of Science, Bangalore.

Anderson K.A., (1958), Phys. Rev. Letters, **1**. 335.

Angell J.K. and Korshover J., (1963), Harmonic Analysis of the biennial zonal wind and temperature regions; *Wexten Memorial Volume*, Monthly, Wea. Rev., **91**, 537.

Bates D.R. and Seaton M.T., (1950) Proc. Phys. Soc., **63**, 129.

Banarjee S.K., (1930), Phil. Trans., **239**, 287.

Bhatnagar V.P. and Mitra A.P., (1966), J. Atmosph. Sci. **23**, 266.

Bolin B. and Keeling C.D., (1963), J. Geophys. Res., **68**, 3899.

Bolin B., (1964), *Research in Geophysics, Vol. 2: Solid Earth and interface phenomena* Edited by Hugh Odishaw, 487.

Cahil L.J., (1959), J. Geophys. Res., 499.

Cahill L.J., (1966), J. Geophys. Res., **71**, 4505.

Chapman S. (1957), *Annals of IGY*, Vol. IV, Part I, 25.

Chapman S. (1957). Bull. Nat. Inst. Sci., No. 9.

Chakravarti, S.K., and Sirkar, D., (1958), Bull. Seismolo. Soc. Amer. 48, 181.

Chakravarti S.K., (1958), J. Sci. Indus. Res., **17A**, Suppl. 100.

Chatterjee J.S., (1961), J. Geophys. Res., **66**, 1535.

De, A.C., (1958), Ind. J. Meteo, Geophys., **9**, 293.

De, A.C., (1959), Ind. J. Meteo, Geophys., **10**, 295.

Dodson H.W. and Hedeman E.R., (1960), List of IGY Flares with normalised values of importance and areas: Solar Activity Series 17, International Geophysical Year, World Data Centre A and published by National Bureau of Standards.

Egedal J. (1948), Nature, **161**, 443.

Ghosh S.N. and Bisht M.S., (1962), Proceedings of IGY Symposium, C.S.I.R., Vol. **2**, 198.

Gill P.S., Lakh Vir, Yadav R.S. and Khera M.K., (1960), Ind. J. Meteo. Geophys., **11**, 169.

Godson W.L., (1960), Quar J. Roy. Meteor. Soc., **86**, 301.

Goel, P.S., Narasappaya N., Prabhakara, C., Rama and Zutshi, P.K., (1958), Tellus, **11**, 91.

Gutnick, M. (1962), '*Mean annual midlatitude profiles to 31 km*' Air Force Cambridge Research Laboratories, Report 147.

Hake, (1973), Stanford Research Institute Reference Atmosphere.

Heliwell R.A., (1960), J. Geophys. Res., **64**, 615.

Hulbert E.O., (1958), Advances in Physics of the Upper Atmosphere since 1950, Naval Research Laboratory, Report 460.

Jangpangi, B.S., (1958), J. Sci. & Ind. Res., **17A**, Suppl., **91**.

Jefferson, D.A., Uppal M.K., Gopalkrishna, J. and Rao, C.V.R., (1982), Proc. Indian Academ. Sci., **48A**, 119.

Johnson C.Y., (1956), Trans. Ameri. Geophys. Union, **37**, 350.

Jones L.M. Peterson J.W., Schaefer E.J. and Schulte H.F., (1959), J. Geophys. Res., **64**, 2331.

Kallman H.K., (1959), J. Geophys. Res., 64, 615.

Kotadia. K.M. and Ramanathan K.R. (1962), Proceedings of IGY Symposium CSIR., Vol. 1, 176.

Krishnamurty M., Sivarama Sastry G. and Seshagiri Rao, T., (1938) J. Sci. Indus. Res., *India* 17A, 71.

Lal D., Malhotra, P.K., and Peters B., (1958), J. Atmos. Terres. Phys., 12, 306.

Lal D., (1959), Ind. J. Meteo. Geophys., 10, 147.

Lal D. and Peters. B., (1962), *Progress in Cosmic ray and Particles Physics. Vol. 6*, North-Holland Publishing Co.

Lal D., (1963), Proc. IGY Symp., Vol. 2, 231.

Little, C.G. and Leinbach, H., (1959), Proc. IRE, 47, 315.

London, J., (1962), '*The distrioution of total ozone in the northern hemisphere*' Mesophere dynamics, Final Report AFCRL 62-672, 68 Department of Meteorology and Oceans.

London, J.K., Ooyama and Prabhakara C., (1962), Mesophere dynamics, Final Report AFCRL 62-672, Geophysics and Research Directorate, AFCRL, Cambridge, Mass ?

Mastenbrook H.J., (1968), J. Atmos. Sci., 25, 299.

Mathur S.B. and Mitra A.P., (1960), J. Sci. Ind. Res., India, 19A, 311.

Maynard. N.C., Cahill L.J. and Sastry T.S.G., (1965), J. Geophys. Res., 70, 5923.

Mitra S.K. (1960), 'Upper Atmosphere and Space Exploration with Satellites', INSA Presidential Addresses, 261.

Mitra A.P., and Shain C.A., (1953), J. Atmos. Terres. Phys., 4, 204.

Mitra A.P. (1959), J. Geophys. Res., 64, 733.

Mitra A.P. (1960), '*Ionospheric Effects of Solar Flares II, Ionization Model*' Sci. Rep. No. 142, Ionosphere Research Laboratory, Pensylvania State University, U.S.A.

Mitra A.P. and Jain, V.C., (1963), J. Geophys. Res., 68, 2367.

Mitra A.P., (1974), *Ionospheric Effects of Solar Flares*; Published by D. Reidel Publishing Company, Dordrecht-Holland.

Mitra A.P., (1982). 'Monograph on Human influences on Atmospheric Environment' P 33, National Physical Laboratory, New Delhi.

Murcray, D.G., Murcray F.H. and Williams W.J., (1962), J. Geophys. Res., 67, 759.

Nerurkar N.W. (1956) Sci., Ph.D Thesis, University of Gujrat.

Nicolet M, (1958), 'Ionospheric Research Laboratory', Pensylvania State Univesity Sci. Rep. 102.

Ogbuhchi P.O. and Onwumechilli, C.A., (1963), J. Geophys., Res., 68, 2421.

Onwumechilli, C.A., (1959), J. Atmos. Terr. Phys., 13, 222.

Onwumechilli, C.A., (1959), J. Atmos. Terr. Phys., 13, 235.

Pant P.S., (1961), Proceedings of IGY Symposium, CSIR, India 1, 7.

Parker, E.N., (1958), Phys. Fluids, 1 171.

Peters, B., (1959), J. Atmos. Terres. Phys. 13, 331.

Paetzold H.K. and Piscalar F., (1961) Naturewissenschaften, 48, 474.

Pishority, P.R., (1959), Ind. J. Meteo. Geophys., 10, 243.

Price A.T. and Stone D.J., (1964), Annals of IGY, Vol. XXXV, 66.

Rao, B.C.N., (1963), J. Geophys. Res., 68, 2541.

Rao, U.R. and Sarabhai, V., (1961), Proc. Roy. Soc. A 263, 101.

Rao, U.R. and Sarabhai, V., (1961), Proc. Roy. Soc., A 263, 118.

Rastogi, R.G., (1962), J. Atmos. Terres. Phys., 24, 1031.

Rastogi R.G., (1963), J. Geophys. Res., **68**, 2445.

Razdan, H., (1962), Proceedings of IGY Symposium, Vol. 2, CSIR 126.

Reed, R.J. and Rogers, D.G., (1962), J. Atmos. Sci., **19**, 127.

Saha, A.K., and Mahajan, K.K., (1964), J. Atmos. Terr. Phys., **26**, 618.

Sarada, K.A. and Mitra, A.P., (1960), 'Some Ionospheric Results obtained during IGY', Elsevier Publishing Company, Amsterdam, **270**.

Sarada, K.A., and Mitra, A.P., (1960), *'Proceedings of IGY Symposium'*, CSIR, India, **1**, 98.

Sastry, T.S.G., 1970), Space Research, **10**, 778.

Sen Gupta, P.R , and Van Allen J.A., (1968), Scientific Report, Department of Physics and Astronomy, University of Iowa, USA.

Shah, G.M , (1961), Proceedings of IGY Symposium, Vol. II, CSIR 98.

[illegible]rd, S.F., (1960). Annals of IGY, Vol. XXXIV, 315.

[illegible]ken T. and Fiske, R.S., (1983), The Volcanic Eruption and its effects: A Centennial Perspective, Smithsonian Institute Press.

Stroud, W.G., Nordberg, W., Branden, W.R., Bateman, F.L. and Titus, P., (1960), J. Geophys. Res., **65**, 2307.

Tandon, A.N., (1957), Ind. J. Meteo. Geophys., **8**, 1.

Tandon A.N., (1961), Proceedings of IGY Symposium, published by CSIR, India Vol. II, 207.

Teweles, S., (1961), Mon. Wea. Rev., **89**, 125.

Teweles, S., (1964), *Research in Geophysics, Vol. 2., Solid Earth and interface phenomena, Edited by Hugh Godishah, 509.*

APPENDIX I

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APPENDIX II

Table 1 *Geographical Distribution of Indian Stations**

		Geographic Latitude	Geomagnetic Latitude	Geographic Longitude	Geomagnetic Longitude
1	2	3	4	5	6
NC. Northern Minauroral Belt					
1.	Machhoi Glacier (near Zoji La)	34°18′N	24°18′N	75°32′E	148°24′E
2.	Srinagar	34°07′N	27°09′N	74°48′E	147°48′E
3.	Gulmarg	34°03′N	24°10′N	74°24′E	147°24′E
4.	Shigri Glacier	32°15′N	22°42′N	77°28′E	149°31′E
5.	Amritsar	31°37′N	22°37′N	74°53′E	148°53′E
6.	Gangotri Glacier	30°55′N	21°06′N	79°04′E	151°04′E
7.	Dehra Dun	30°20′N	20°43′N	78°03′E	150°03′E
Equatorial Belt					
8.	Naini Tal	29°23′N	19°30′N	79°27′E	151°10′E
9.	Delhi	28°38′N	19°11′N	77°13′E	148°55′E
10.	Darjeeling	27°03′N	16°24′N	88°16′E	159°16′E
11.	Chatra	26°50′N	16°24′N	87°10′E	158°10′E
12.	Toklai	26°45′N	15°45′N	94°15′E	164°24′E
13.	Jodhpur	26°17′N	17°17′N	73°02′E	145°02′E
14.	Gauhati	26°10′N	15°10′N	91°45′E	162°24′E
15.	Shilong	25°34′N	14°34′N	91°53′E	162°23′E
16.	Allahabad	26°27′N	15°28′N	81°54′E	152°50′E
17.	Banaras	25°20′N	15°20′N	83°01′E	154°01′E
18.	Mt Abu	24°36′N	15°36′N	72°43′E	144°21′E
19.	Bokaro	23°50′N	13°40′N	85°48′E	156°34′E
20.	Kandla	23°01′N	14°01′N	70°13′E	141°12′E
21.	Ahmedabad	23°01′N	14°01′N	72°36′E	143°50′E
22.	Navalakhi	22°58′N	13°58′N	70°27′E	141°53′E
23.	Mundra	22°44′N	13°47′N	69°46′E	141°09′E

(*Contd. on page 145*)

*Data are also collected by ships in the Indian Ocean, the Bay of Bengal and the Arabian Sea.

Appendix II (*Contd. from page 144*)

1	2	3	4	5	6
24.	Haringhata	22°58′N	12°15′N	88°34′E	158°42′E
25.	Calcutta	22°34′N	11°54′N	88°21′E	158°27′E
26.	Garden Reach	22°33′N	11°53′N	88°18′E	158°24′E
27.	Diamond Harbour	22°12′N	11°34′N	88°10′E	158°13′E
28.	Bhavnagar	21°48′N	12°47′N	72°09′E	143°09′E
29.	Sagar (West Bengal)	21°39′N	11°02′N	88°03′E	158°03′E
30.	Nagpur	21°09′N	11°20′N	79°06′E	150°06′E
31.	Veraval	20°54′N	11°54′N	70°23′E	141°23′E
32.	Mahanadi river mouth	20°25′N	10°04′N	86°47′E	156°47′E
33	Bombay	19°00′N	10°00′N	72°50′E	143°53′E
34.	Alibag	18°38′N	09°38′N	72°53′E	143°50′E
35.	Poona	18°31′N	09°31′N	73°52′E	144°52′E
36.	Vizianagram	18°07′N	08°70′N	83°27′E	153°27′E
37.	Hyderabad	17°26′N	07°45′N	78°27′E	148°40′E
38.	Visakhapatnam-Waltair	17°43′N	07°43′N	83°18′E	153°18′E
39.	Ratnagiri	16°59′N	07°59′N	73°18′E	143°58′E
40.	Rangoon	16°46′N	05°46′N	90°10′E	160°10′E
41.	Moulmein	16°29′N	05°29′N	97°37′E	167°06′E
42.	Khartoum	15°35′N	13°04′N	32°35′N	104°27′E
43.	Dharwar	15°27′N	06°27′N	75°01′E	145°01′E
44.	Madras	13°05′N	03°05′N	80°17′E	150°17′E
45.	Bangalore	12°58′N	03°26′N	77°38′E	147°38′E
46.	Mangalore	12°51′N	03°51′N	74°50′E	144°50′E
47.	Aden	12°47′N	07°47′N	44°59′E	111°59′E
48.	Chidambaram	11°24′N	01°28′N	79°42′E	149°42′E
49.	Tiruchirapalli	10°49′N	01°05′N	78°42′E	148°42′E
50.	Kodaikanal	10°14′N	00°44′N	77°29′E	147°29′E
51.	Cochin	09°58′N	00°43′N	76°16′E	146°15′E
52.	Mandapam	09°17′N	00°33′N	79°08′E	148°46′E
53.	Trivandrum	08°29′N	00°54′S	76°57′E	146°11′E
54.	Port Blair	11°40′N	00°40′N	92°46′E	161°46′E
55.	Minicoy	08°19′N	00°41′S	73°04′E	142°14′E
56.	Singapore	01°17′N	09°43′S	103°51′E	172°51′E

APPENDIX III

Table 1 *Geographic and Magnetic Co-ordinates of Indian Ionospheric Stations*

Station	Geographical Co-ordinates		Geomagnetic Latitude	Magnetic Dip	Sub-jects
Delhi	28°38′N,	77°13′E	19°11′N	42.4°N	abcd
Banaras	25°20′N,	83°01′E	15°20′N	37.1°N	ab
Ahmedabad	23°01′N,	72°36′E	14°01′N	34°N	abc
Haringhata (Calcutta)	22°58′N,	88°34′E	12°15′N	32°N	ab
Bombay	19°00′N,	72°50′E	10°00′N	24.75°N	a
Poona	18°31′N,	73°52′E	09°31′N	24.5°N	d
Waltair	17°43′N,	83°18′E	07°43′N	20.4°N	c
Madras	13°05′N,	80°17′E	03°05′N	10.5°N	ab
Tiruchirapalli	10°49′N,	78°42′E	01°05′N	4 8°N	a
Kodaikanal	18°14′N,	77°29′E	00°44′N	3.5°N	a
Trivandrum	08°29′N,	76°57′E	00°54′S	0	a

a : Vertical-incidence Sounding
b : Absorption—A1 technique
c : Drift measurements
d : Absrption : Cosmic noise measurement

A. Special Lectures

Mitra, S.K. (1960), Upper Atmosphere and Space Exploration with artificial satellites, Presidential Address, Indian National Science Academy.

Mitra, S.K., (1963), Physics of the Earth's Outer Space, Seventh Meghnad Saha Memorial Lecture.

Saha, M.N., (1939), Solar Control of the Atmosphere, Presidential Address, Indian National Science Academy.

Ramanathan, K.R., (1954), Atmospheric Ozone and the General Circulation of the atmosphere, Presidential Address at 10th Gen. Assembly, Rome.

Ramanathan, K.R., (1939), The Earth's Magnetism and the Upper Atmosphere, Presidential Address, Section on Physics and Mathematics, Indian Science Congress.

Ramanathan, K.R., (1969), Sisir Kumar Mitra Memorial Lecture, Proc. Nat. Inst. Sci., 35A (2), 268.

Mitra, A.P., (1972), The Earth's Near Space Environment, Presidential Address, Physics Section, Indian Science Congress, Calcutta.

B. IGY Publications Outside India

1. Annals of the International Geophysical year.

Vol. I	The Histories of the International Polar Years and the Inception and Development of the International Geophysical Year
Vol. IIA	The Development of the International Geophysical Year. Reports of CSAGI Meetings at which the International Geophysical Year Plans were elaborated. Editor : M. Nicolet.
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Vol. XLVII	Selected IGY Magnetograms : Editor : V. Laursen.

2. Contributions in Geophysics (in honour of Bono Gutenberg) Pergamon Press, Oxford, England (1959).
3. Cumulus Dynamics, edited by C.E. Anderson, Air Force Cambridge Research Centre U.S.A. (1960) Pergamon Press, Oxford, England.
4. Dynamics of climate, edited by R.L. Pfeffer, Geophysics Research Directorate, Boston (1960) Pergamon Press, Oxford, England.
5. Earth's Core and Geomagnetism, J.A. Jacobs University of British Columbia, Pergamon Press, Oxford, England.
6. The Planet Earth, Edited by D.R. Bates, F.R.S. The Queens University, Belfast (1957) Pergamon Press, Oxford, England.
7. Recent Advances in Atmospheric Electricity, edited by L.G. Smith, Air Force Cambridge Research Centre U.S.A. (1958) Pergamon Press, Oxford, England.
8. Research in Geophysics, : Volume 1. Sun, upper Atmosphere and Space (1964) MIT Press, Massachusatts Institute of Technology, Cambridge, Mass., USA.
9. Research in Geophysics : Volume 2. Solid Earth and Interface Phenomena, edited by Hugh Odishaw, MIT Press, Massachusetts Institute of Technology, Cambridge, U.S.A.

SPECIAL INDIAN IGY PUBLICATIONS

1. Indian National Committee for the IGY (1958) : Work carried out under the Auspices of the National Committee for the IGY 1957-58", *J. Sci. & Ind. Res., Supplement*, **17** (12), 1-110.
2. Indian National Committee for the IGY (1962) : *Proceedings of IGY Symposium*, Vol 1 & 2 N.P.L., New Delhi.
3. Mitra, A.P., (1974), *Ionospheric Effects of Solar Flares*, D. Reidel Publishing Co. Holland, VIII.
4. Indian National Committee for the IGY (1957) *Bulletin* 1, *Indian Programme*, N.P.L. New Delhi.
5. Indian National Committee for the IGY (1957); *Bulletin* 2, *Auroral observations during the IGY in Middle and Low Latitudes*, N.P.L., New Delhi.
6. Indian National Committee for the IGY (1957); *Bulletin* 3: *Ionospheric Measurements I*, N.P.L., New Delhi.
7. Indian National Committee for the IGY (1957); *Bulletin* 4: *Plan for the Despatch of Indian Data to WDC*, N.P.L., New Deihi.
8. Indian National Committee for the IGY (1958); *Bulletin* 5: *Ionospheric Measurements II*, N.P.L., New Delhi.
9. Indian National Committee for the IGY (1958); *Bulletin* 6 : *Progress Report July 1957—March 1958*, N.P.L. New Delhi.

WORLD DAYS

1. Sundaram, V. (1958), *URSI Inf. Bull.*, **112**, 69.

AURORA & AIRGLOW

1. Angreji, P.D. (1962), in "*Proceedings of IGY Symposium*. Vol 2". CSIR, 112.
2. Chiplonkar, M.W. and Kulkarni, P.V. (1959), *J. Geophys. Res.* **64**, 1641.
3. Chiplonkar, M.W. and Kulkarni, P.V. (1958), *Ind. J. Met. Geophys.*, **9**, 133.
4. Dandekar, B.S. (1962), in "*Proceeding of IGY Symposium*, Vol 2",.CSIR, 88.
5. Dandekar, B.S. (1962) in "*Proceedings of IGY Symposium*. Vol 2". CSIR, 119.
6. Kulkarni, R.N., Angreji, P.D. and Ramanathan, K.R. (1959), *Met. & Geophys., Japan*, **10**, (2), 85.
7. Kulkarni, P.V. (1958), Ph.D. Thesis, Poona University.
8. Ramanathan, K.R. and Dave, J.V. (1957), *Ann. IGY*, **5**, 23.
9. Shah, G.M. (1962), in "*Proceedings of IGY Symposium*, Vol 2", CSIR 98.

METEOROLOGY

1. De, A.C. (1958), *Ind. J. Met. Geophys.* **9**, 293.
2. Jagannathan, P. and Alvi, S.M.A. (1964), *Ind. J. Met. Geophys.*, **15** (2), 251.
3. Jagannathan, P., Das, U.S. and Datar, V.V. (1964), *Ind, J. Met. Geophys.*, **15** (1).
4. Krishnan, A., Pant, P.S. and Ananthakrishnan, R. (1961) *Ind. J. Met. Geophys.*, **12**, 431.
5. Lal, D. Malhotra, P.K. and Peters, B. (1958), *J. Atmosph. Terr. Phys.* **12**, 306.

6. Lal, D. (1959), *Ind. J. Meteor. Geophys.*, **10**, 147.
7. Mani, Anna and Chacko, Oommen, (1962), *Proc. IGY Symp* , **Vol 2**, 54.
8. Mani, Anna and Chacko, Oommen, (1962), *Proc. IGY. Symp.*, **Vol 2**, 46.
9. Mani Anna, Chacko, Oommen and Venkiteshwaran, S.P., (1962), *Ind. J. Met. Geophys*, **13**, 337.
10. Padmanabhamurty, B. and Subrahmanyam, V.P. (1962), *Proc. IGY Symp.*, **Vol 2**, 42.
11. Pant, P.S., (1962), *Proc. IGY Symp.*, **Vol 2**, 7.
12. Pant, P.S., and Vernekar, A.D., (1962), *Proc. IGY Symp.*, **Vol 2**, 20.
13. Peters, P., (1959), *J. Atmosph. Terr. Phys* , **13**, 351.
14. Pisharoty, P.R., (1959), *Ind. J. Meteor. Geophys.*, **10**, 243.
15. Ramanathan, K.R., and Dave, J.V., (1957), *IGY Annuals*, 5, 23.
16. Ramanathan, K.R. and Kulkarni, R.N., (1960), *Qly. J. Roy. Meteorol. Soc.*, **86**, 144.
17. Rao, K.N. (1958), *Proc. of Symposium on Monsoons of the World*, New Delhi, 43.
18. Sachdev, D.K., (1958). *J. Sci. Ind Res. India*, **17A**, 262.

GEOMAGNETISM

1. Bhargava, B.N. and Subrahmanyan, R.V. (1961), *J. Atmos. Terrest. Phys.* **20**, 81.
2. Bhonsle, R.V. and Ramanathan, K.R., (1960), *Planet. Space Sci*, **2**, 99.
3. Chatterjee, J.S., (1962), in "*Proceedings of IGY Symposium*, Vol 1" CSIR 86.
4. Chatterjee, J.S., (1961), *J. Geophys Res.* **66**, 1535.
5. Iyengar, R.S., (1964), *Nature*, **202**, 372.
6. Malurkar. S.L., (1958), *J. Sci. Ind. Res., India*, **17** (12), 33.
7. Pisharoty, P.R. and Joseph, P.V., (1962), *Proc. IGY Symp.*, **Vol 2**. 70.
8. Pramanik, S.K. and Yegnanaryanan, S., (1962), *J. Meteorol. Geophys.*, **3**, 212.
9. Radhakrishnamurty, C. and Sahasrabudhe, P.W., (1962), in "*Proceedings of IGY Symposium*, Vol 2", CSIR, 188.
10. Raja Rao, K.S., (1961), *J. Atmosph. Terr Phys.*, **20**, 289.
11. Raja Rao, K.S., (1960) in "*Proceedings* of *IGY Symposium*, Vol 1", 86.
12. Raja Rao, K.S., and Shivaraman K.R., (1958), *J. Geophys. Res.* **63**, 727.
13. Raja Rao, K.S., (1960), *J. Atmosph. Terr. Phys.*, **65**, 119.
14. Rastogi, R.G., (1961), *J. Atmosph. Terr. Phys.*, **22**, 290.
15. Rastogi, R.G., (1962), *J. Atmosph. Terr. Phys.*, **24**, 1031.
16. Rastogi, R.G , (1962), *J. Res. NBS, Radio Prop.*, **66 D**, 601.
17. Shirgaokar, A.J. and Srivastava, B.J., (1962), *Proc. IGY Symp.*, **Vol 2**, 74.
18. Srivastava, B.J., (1962), *Proc. IGY Symp.*, **Vol 2**, 78.
19. Yacob, A. and Khanna, K.B., (1964), *Indian J. Meteor. Geophys.*, **15** (1) 83.
20. Yacob, A. and Pisharoty, P.R., (1962), *Proc. IGY Symp.*, **Vol 2**, 85.
21. Yacob, A., (1962), *Proc. IGY Symp.*, **Vol 2**, 84.

IONOSPHERE

1. Aggarwal, K.K., (1959), *J. Inst. Telecomm. Engrs*, **5**, 232.
2. Aiya, S.V.C., (1958), *Proc. Inst. Radio Engrs, N Y.*, **46**, 580.
3. Aiya, S.V.C., (1958), *Proc. Inst. Radio Engrs, N.Y.*, **46**, 1502.
4. Aiya, S.V.C., (1959), *Proc. Inst. Radio Engrs*, **47**, 92.
5. Aiya, S.V.C., (1958), *J. Sci. Industr. Res.*, **17B**, 337.
6. Aiya, S.V.C., (1959), *J. Sci. Ind. Res.*, **18B**, 44.

7. Aiya, S.V.C., Phadke. R.K. Padmanabhan, S.V. & Sane, C.K., (1959) *J. Sci. Ind. Res.*, **18B**, 47.
8. Aiya, S.V.C. & Khot, C.G., (1959), *J. Sci. Ind. Res.*, **18B**, 54.
9. Aiya, S.V.C., (1960), *Proc. Inst. Radio Engrs., N.Y.*, **48**, 955.
10. Aiya, S.V.C., (1958), *J. Instn Telecomm. Engrs*, **4**, 81.
11. Bandopadhyay, P., (1960), *J. Atmos. Terr.* Phys , **18**, 132.
12. Bandopadhyay, P., (1959), *J. Atoms. Terr. Phys.*, **16**, 84.
13. Bandopadhyay, P. & Chatterjee, S.K., (1961), *Indian J. Phys* , **35**, 240.
14. Bandopadhyay, P. & Chatterjee, S.K., (1962), *Indian J. Phys* , **45**, 124.
15. Banerjee, R.B., (1960), *Proc. Phys. Soc.* **76**, 959.
16. Banerjee, R.B., (1958), *J. Atmosph. Ter. Phys.* **12**, 248.
17. Bhargava. B.N. & Subrahmanyan, R.V., (1961), *J. Atmos. Terr. Phys.*, **20**, 814.
18. Bhargava, B.N. & Subrahmanyan, R.V., (1960), *Indian J. Met. Geophys.*, **11**, 363.
19. Bhargava, B.N., (1959), *Indian J Met. Geophys.*, **10**, 69.
20. Bhargava, B.N. & Gopala Rao, Y.V., (1959), *Indian J Met. Geophys.*, **10**, 203.
21. Bhonsle, R.V., (1960), Ph D. Thesis, Gujrat University.
22. Bhonsle, R.V. & Ramanathan, K.R., (1958), *J. Sci. Ind. Res.* **17A**, 40.
23. Bhonsle, R.V. and Ramanathan, K.R., (1969), *Planetary Space Sci*, **2**, 95.
24. Chatterjee B., (1959), *J Instn. Telecomm. Engrs*, **6**, 47.
25. Chiplonkar, M.W., Karekar, R.N , Raju, T.A. & Hattiangadi, M.S., (1958), *J. Sci. Ind. Res , Suppl*, 17A., 3.
26. Das Gupta, P. & Vij, K.K., (1960), *J. Atmos Terr. Phys* , 18, 265.
27. Datta, S., (1958), *Indian J. Phys.*, **32**, 493.
28. Datta, S. & Datta, R.N., (1959), *Indian J. Phys.*, **38**, 316.
29. Datta, S., Bandopadhyay, P. & Datta R.N , (1959), *J. Atmos. Terr. Phys.*, **16**, 182.
30. Datta, S., (1960), *Indian J. Phys.*, **34**, 66.
31. Ghosh, B.B. & Mitra, S.N., (1959), *Tech. Conv. Instn. Telecomm. Engrs* (India).
32. Ghosh, S.N. & Nand, S., (1960), *Indian J. Phys.* **34**, 516.
33. Ghosh, S.N. & Malaviya, V., *J. Atmos. Terr. Phys.* **217**, 243.
34. Khastgir, S.R., (1958), *Nature Lond.*, **181**, 1679.
35. Kotadia, K.M., (1958), *J. Sci. Ind. Res.*, **17A**, 46.
36. Kotadia, K,M., (1959), *Proc. Indian. Acad. Sci* , **50A**, 259.
37. Kotadia, K.M. & Ramanathan, K.R., (1961), *Ann. IGY*, **11**, 68.
38. Krishnamurthi. M., Sastry, G.S. & Rao, T.S , (1958), *J. Sci. Ind. Res.*, **17A**, 71.
39. Kundu, M.R., (1959), *Nature., Lond* **183**, 1047.
40. Kundu, M.R., (1959), *J. Instn. Telecomm. Engrs*, **5**, 77.
41. Lakashmi Bai, C., (1958), *J. Sci. industr. Res.*, **17B**, 83.
42. Mahajan, K.K. and Mitra, A P. (1962), *Proc. IGY Symp.* **Vol 1**, 57.
43. Mathur, S.B. & Mitra, A.P., (1960), *J. Sci. Ind. Res.* **19A**, 311.
44. Mazumdar, S.C., (1958), *J. Instn. Telecomm. Engrs*, **4**, 81.
45. Mitra A.P., (1957), *J Atmos. Terr. Phys.* **10**, 140.
46. Mitra, A.P. (1957), *J. Atmos. Terr. Phys.*, **10**, 153.
47. Mitra, A.P., (1957), *J. Sci. Ind. Res.*, **16A**, 327.
48. Mitra, A.P., (1957), *J. Instn. Telecomm. Engrs*, **3**, 198.
49. Mitra, A.P., (1958), *J. Sci. Ind. Res.*, **17A**, 395.

50. Mitra, A.P., Sarada, K.A., Sarma, N V.G. & Joshi, M.N , (1958), *J. Sci. Ind.* Res., **17A**, 74.
51. Mitra, A.P., (1958), *J. Sci. Ind. Res.*, **17A**, 34.
52. Mitra, A.P., (1959), *J. Geophys. Res.* **64**, 733.
53. Mitra, A.P., (1958), *Sci Rep. ions. Res. Lab. Pensyl. St. Univ.*, No. 112.
54. Mitra, A.P. & Sarada, K.A., (1961), *Radio Res. Com. Sci. Rep.* No. 147.
55. Mitra, A.P., (1960), *Sci. Rep. ionos. Res. Lab. Pensyl. St. Univ.*, Nov. 142.
56. Mitra, A.P., (1961), *Sci. Rep. ionos. Res. Lab. Pensyl. St Univ.*, No. 147.
57. Mitra, A P., (1961), *J. Sci. Ind. Res.*, **20A**, 409.
58. Mitra. A.P., (1962), *Proc. IGY Symp.*, **Vol I**, 1.
59. Mitra, S.N., Rao, B.C.N., (1959), *Indian J. Phys.*, 33, 540.
60. Mitra, S.N. & Vij, K.K., (1960) *J. Instn. Telecomm. Engrs*, **6**, 90.
61. Mitra, S.N., Vij, K.K. & Dass Gupta, P., (1960), *J. Atmos. Terr. Phys.*, **19**, 172.
62. Mitra, S.N. & Ghosh, B.R., (1958). *J. Instn. Telecomm. Engrs*, **5**, 2.
63. Mitra, S.N., (1959), *J. Instn. Telecomm. Engrs.* **5**, 121.
64. Mitra, S.N. & Ghosh, B.B., (1959), *J. Instn. Telecom. Engrs.* **5**, 194.
65. Rao, B.C. Narasinga (1963), *J. Geophys. Res.*, **68**, 2541.
66. Rao, B.C. Narasinga (1965), Ph.D. Thesis, Andhra University.
67. Murty, Y.S N., (1959), *Sci & Cult.*, **25**.
68. Murty, Y.S.N. & Khastgir, S R., (1959), *Proc. Nat. Inst. Sci. India.*
69. Murty, Y.S.N., Singh, R.N. & Khastgir, S.R., (1959), *J. Sci. Ind. Res.*, **18A**.
70. Murty, Y.S.N. & Khastgir, S.R., (1960), *J. Atmos. Terr. Phys.*, **21**, 65.
71. Parthasarthy, R., (1957). *J. Instn. Telecomm. Engrs.*, **5**, 242.
72. Parthasarthy, R. & Sarada, K.A., (1958), *Indian J. Telecom. Engrs.*, **4**, 115.
73. Ramana, K.V.V. & Rao, B.R., (1961), *J. Atmos. Terr. Phys.*, **22**, 1.
74. Ramanathan, K.R. (1957), *J. Inst. Telecomm. Eng., India*, **3**, (3), 193.
75. Ramanathan, K.R., & Bhonsle, R.V., (1959), *J. Geophys. Res.*, **64**, 1635.
76. Ramanathan, K.R., Bhonsle, R.V. and Degaonkar S.S., (1961), **1**. *Geophys. Res.*, **66**, 2763.
77. Rao, B.R. and Rao, E.B., (1957), *C.R, du 3e congress de la F.I.G.S.A. Tanarive*, A. 71.
78. Rao, B.R. & Rao E.R., (1958), *Nature, Lond.*, 181, 1612.
79. Rao, B.R. & Ramana, K.V.V. (1958), *J. Sci. Ind. Res.*, **17A**. 56.
80. Rao, B.R. & Rao, E. (1959), *J. Atmos. Terr. Phys* , **14**, 94.
81. Rao, B.R., Rao, E.B. & Pant, P.R.R., (1959), *Nature, Lond.*, **183**. 667.
82. Rao, B.R. & Ramana, K.V.V., (1961), *Nature, Lond.*, **190**, 706.
83. Rao, B.R. & Rao, R.R., (1961), *J. Atmos. Terr. Phys.*, **21**, 208.
84. Rao, B.R. & Murty, D.S., (1958), *J. Sci. Ind. Res.*, *Suppl.* **63**.
85. Rao, B.R., Rao, M.G.S., Murty., (1961), *Indian J. Phys*, **35**, 475.
86. Rao, B.V.T. & Rao M.K., (1958), *J. Instn. Telecomm. Engrs.* **4**, 205.
87. Rao, C.S.R. & Bhargava, J.C., (1960), *Indian J. Phys.*, **34**, 85.
88. Rao, C.S.R. & Ranganathan, T.N., (1960), *J. Instn. Telecamm. Engrs.* **6**, 161.
89. Rao, C.S.R. & Bose, S.C., (1961), *J. Instn. Telecomm Engrs.*, **7**.
90. Rao, C.S.R. & Sain, M. (1962), *J. Instn. Telecomm. Engrs* . **8**, 177.
91. Rao, C.V.S. & Mitra S.N., (1962), *J. Geophps. Res.*, **67**, 127.
92. Rao, C.V.S. *Ionosphere over Trivandrum: Part IV-Spread F over.*
93. Rao, E.B. & Rao B.R., (1961), *Curr. Sci*, **80**, 9.
94. Rao, E.B. & Rao, B.R. (1961), *J, atmos. terr. Phys*, **20**, 296.
95. Rao, E.B. & Rao, B.R.) 1961), *J. Sci. Ind. Res.*, **20B**, 301.
96. Rao, M.K., (1960), *J. Instn. Telecomm. Engrs.* **6**, 265.

97. Rao, M.K., Mazumdar, S.C. & Mitra S.N., (1962), *J. Atmos. Terr. Phys.*, **24**, 245.
98. Rao, M.N. & Mitra, A.P., (1958), *J. Atmos. Ter. Phys.*, **18**, 271.
99. Rao, M.S.V.G., Rao, B.R. & Pant, P.R.R., (1960), *J. Atmos Terr. Phys.* **17**, 345.
100. Rao, M.S.V.G., Rao, B.R. & Pant, P.R.R. (1960), *Curr. Sci.* **9**, 304.
101. Rao, M.S.V.G. & Rao, B.R., (1961), *Canad. J. Phys.*, **39**, 396.
102. Rao, M S.V.G. & Rao, B.R., (1961), *J. Geophys. Res.*, **66**, 2113.
103. Rao, M.S.V.G. & Rao, B.R., (1961), *J. Atmos Terr. Phys.*, **22**, 12.
104. Rao, R.R. & Rao, B.R. (1960), *Nature, Lond*, **185**, 27.
105. Rao, R.R. & Rao, B.R., (1961), *J. Atmos. Terr, Phys.*, **22**, 81.
106. Rao, R.R. & Rao, B.R., (1961), *J. Atmos. Terr. Phys*, **22**, 158.
107. Reddy, C.A. & Rao, B.R. (1962), *J. Atmos. Terr. Phys.*, **24**, 401.
108. Rastogi, R.G., (1958), *Geofis. pur. appl.* **40**, **Part II**, 145.
109. Rastogi, R.G. (1959), *J. Geophys. Res.*, **64**, 727.
110. Rastogi, R.G., (1959), *Can. J. Phys.*, **37**, 874.
111. Rastogi, R.G. (1959), *Proc. Symposium on Physical Processes in Sun-Earth Environment held at Ottawa*, July 20-21.
112. Rastogi, R.G., (1959), *J. Atmos. Terr. Phys.*, **14**, 33.
113. Rastogi, R.G., (1960), *J. Geophys. Res.*, **65**, 857.
114. Rastogi, R.G., (1960), *J. Geophys. Res.*, **65**, 585.
115. Rastogi, R.G., (1961), *Nature*, **189**, 214
116. Sachdev, D.K., (1958), *J. Sci. Ind. Res.*, **17A**, 262.
117. Sachdev, D.K., *Radio Res. Com. Sci. Rep.* No. 7.
118. Saha, A.K., (1959), *J. Instn. Telecomm. Engrs.*, **5**, 136.
119. Sarada, K.A. and Mitra, A.P. (1962), *Proc. IGY Symp.* Vol. **1**, 158.
120. Sarada, K.A. (1958), *J. Atmos. Terr. Phys.*, **13**, 192.
121. Sarada, K.A. & Mitra, A.P. (1960), *URSI Monograph* No. **1**, 270.
122. Satyanarayanmurthy, C.H. (1962), *Proc. IGY Symp.* Vol. **1**, 48.
123. Satyanarayan, S., Bhakru, K & Khastgir, S.R., (1959), *J. Atmos. Terr. Phys.*, **13**, 201,
124. Sethuraman, R., (1958), *Proc. Indian Acad. Sci.*, **42A**, 84.
125. Sethuraman, R. (1958), *J. Sci. Ind. Res.*. **17A** *Suppl.* 50
126. Setty, C.S.G.K. and Kamal, I.R., (1962), *Proc. IGY Symp.* Vol. **1**, 64.
127. Setty, C.S.G.K. (1960), *J. Atmos. Terr. Phys.*, **19**, 88.
128. Setty C.S.G.K. (1960), *J, Atmos. Terr. Phys.*, **19**, 82.
129. Shirke, J.S., (1959), *Proc. Instn. Telecomm. Engrs*, **5**, 115.
130. Singh, R.N. & Murty Y.S.N. (1959), *J. Sci. Res., Banaras Hindu Univ.*, **9**.
131. Singh, R.N. & Khastgir, S.R. (1959), *J. Atmos. Terr. Phys.*, **16**, 376.
132. Singh, R.N. & Ram, R.L., (1958), *J. Atmos. Terr. Phys.*, **13**, 190.
133. Singh R.N. & Murthy, Y.S.N., (1958), *Curr. Sci.*, **27**, 161.
134. Somayjulu, Y.V. & Rao, N.N. (1958), *J. Sci. Ind. Res.*, **17A**, 54.
135. Somayajulu, Y.V. (1963) *J. Geophys. Res.*, **68**, 1899.
136. Somayajulu, Y.V. (1963), *Penn. State Univ. Ionosoph. Res. Lab. Sci. Rep.* No. 192, 1963.
137. Srivastava, R.S. & Khastgir, S.R. (1959), *J. Sci. Ind. Res.*, **18A**, 426.
138. Suryanarayana, R.K., (1961), *J. Atmos. Terr. Phys.*, **24**, 57.
139. Tandon, J.N. (1958), *Indian J. Phys.*, **32**, 317.
140. Tantry, B.A.P. & Srivastava, R.S., (1958) *Sci. & Cult.*, **23**, 373.
141. Tantry, B.A.P., (1958), *Indian J. Phys*, **32**, 267,
142. Tantry, B.A.P. & Srivastava, R.S., (1958), *Proc. Nat Inst. Sci. India*, **24A**, 217.
143. Tantry, B.A.P. & Srivastava, R.S., (1958), *J. Atmos. Terr. Phys.*, **13**, 38.
144. Tantry, B.A.P. & Srivastava, R.S. (1958), *J. Sci. Ind. Res.*, **17B**.

145. Venkateswarlu, P. & Satyanarayan, R., (1961), *J. Sci. Ind. Res.*, **20B**, 8.
146. Venugopal, V.R., (1958), *Indian J. Met. Geophys.*, **10**, 325.
147. Venugopal, V.R., (1959), *Bull. Kodaikanal Obs.* **51**, 1.

SOLAR ACTIVITY

1. Krishnamurthy, M., Sastry, G.S. and Rao, T.S., (1958). *J. Sci. Ind. Res., India*, **17** (12), *Suppl.* 71.
2. Krishnamurthi, M. and Ramakrishna, S. (1962), *Proc. IGY Symp.* **Vol. 1**, 212.
3. Kundu, M.R. (1961), *J. Geophys. Res.*, **66**, 4308.
4. Kundu, M.R. (1961), *Astrophys. J.* **134**, 96.
5. Kundu, M.R., Roberts, J.A., Spencer, C.L. and Kuiper, J.W. (1961), *Astrophys. J.*, **133**, 255.
6. Malurkar, S.L., (1958), *J. Sci. Ind. Res., India*, **17** (12) *Suppl.* 69.
7. Mitra, A.P., Sarada, K.A., Sarma, N.V.G. and Joshi, M.N., (1958), *J. Sci. Ind. Res, India* **17**(12) *Suppl.* 74.
8. Parthasarathy, R, (1959), *The observatory*, **79**, 65.
9. Rao, B.R. and Rao, E.B. (1958), *J. Sci. Ind. Res., India*, **17** (12), Suppl. 59.
10. Sarada, K.A. and Mitra, A.P., (1962), *Proc. IGY Symp.* **Vol. 1**, 158.

COSMIC RAYS

1. Ahluwalia, H.S. (1962), in "*Proceedings of IGY Symposium*, Vol. 2" 139,
2. Appa Rao, M.V.K., (1961), Rept. N.YO-9553, Univ. Rochester Dept. Phys. & Astron.
3. Appa Rao, M.V.K. & Kaplan, M.F. (1962), *J. Phys. Soc. Japan*, **17**, Suppl. A-3, 48.
4. Appa Rao, M.V.K., Biswas, S., Daniel, R.R., Neelakantan, K.A. & Peters, B. (1958), *Phys. Rev.*, **110**, 751.
5. Bhavsar, P.D. and Sarabhai, V.A., (1958), *Nuovo Cim., Suppl.* **8**, 299.
6. Bhavsar, P.D. (1962), *J. Geophys, Res.*, **67**, 2627.
7. Biswas, S., Lavakare, P.J., Nilakantane, K.A. and Shukla, P.G., (1960) *Phys. Rev.*, **118**, 591.
8. Biswas, S., (1962), *J. Geophys. Res.*, **67**, 2613.
9. Daniel, R.R., Menon, M.G.K. and Sreekantan, B.V., (1959) *Curr. Sci.*, **28**, 389.
10. Gill, P.S., Vir Lekh., Yadav, R.S. and Khera, M.K., (1960), *Ind. J. Meteor. Geophs*, **11**, 169.
11. Goel, P.S., Narsappaya, N., Prabhakara C., Rama and Zutshi, P.V. (1959) *Tellus*, **11**, 91.
12. Lal, D. and Peters, B., (1962), in *Progress of Cosmic Ray Physics and Elementary Particles Physics*. Vol. **6**, North Holland, 1.
13. Lal D., Malhotra, P.K. and Peters, B., (1958), *J. Atmosph. Phys.*, **12**, 306.
14. Lal, D., (1963), in "*Proceedings of IGY Symposium*, **Vol. 2**", CSIR 231.
15. Peters, B., (1958), *L'age Nuclaire*, **9**, 57.
16. Peters, B., (1958), *L'age Nuclaire*, **10**, 117,
17. Peters, B., (1959), *J. Geophys. Res*, **64**, 155.
18. Peters, B., (1958), *Nuovo Cimento, Suppl.* **8**, 556.
19. Rao, U.R. and Sarabhai, V., (1961) *Proc. Roy. Soc.*. A **263**, 101.
20. Rao, U.R. and Sarabhai, V., (1961), *Proc. Roy. Soc.*, A **263**, 118.
21. Rao, U.R., (1963), in "*Proceedings of IGY Symposium*. **Vol. 2**", CSIR, 132.

22. Rao, U.R. and Sarabhai, V., (1961), *Proc. Roy. Soc.*, A **263**, 127.
23. Rao, U.R., McCracken, K.G. and Venkatesan, D., (1963), *J. Geophys. Res.* **68**, 345.
24. Razdan, H., (1962), in "*Proceedings of IGY Symposium*, **Vol. 2**" CSIR, 126.
25. Sarabhai, V.A., (1959), in "*Proceedings of Cosmic Ray Symposium, Bombay*", 1959.
26. Sarabhai, V.A., (1963), *J. Geophys Res.*, **68**, 1955.
27. Satyaprakash and Sarabhai, V.A. (1960), *Proc. Ind. Acad. Sci.* **51**, 84.
28. Subrahmanyam A., Naraman, S., Ramanamurthy, P.V., Sahiav, A.B. and Lal, S., (1958), *Nuovo Cim*, **7**, 110.
29. Subrahmanyam, A. and Verma, S.D, (1959), *Nuovo Cim.*, **13**, 572.

LONGITUDES AND LATITUDES

1. Mathur, K.N. and Rangan, C.S., (1958), *J. Sci. Ind. Res., India* **17** (**12**), *suppl.* 83.
2. Vainu Bappu, M.K., (1958), *J. Sci. Ind. Res. India*, **17** (12), *Suppl.* 80.

GRAVIMETRY

1. Balakrishna, S. and Hayakawa, M., (1962), in "*Proceedings of IGY Symposium*, Vol. 2," CSIR, 174.
2. Chugh, R.S., (1962), in "*Proceedings of IGY Symposium*. Vol. 2", CSIR 140.
3. Hayakawa, M. and Balakrishna, S., (1962), in "*Proceedings of IGY Symposium*, Vol. 2," CSIR, 164.

GLACIOLOGY

1. Jangapangi, B.S., (1958), *J. Sci. Ind. Res., Iudia*, **17** (12), *Suppl.* 91-93.

ROCKETS AND SATELLITES

1. Vainu Bappu, M.K., (1958), *J, Sci. Ind. Res., India*, **17** (12) *Suppl.* 95.
2. Mathur, S.B. and Mitra, A.P., (1960), *J. Sci. Ind. Res.*, **19A**, 311.

OCEANOGRAPHY

1. Chugh, R.S., (1962), in "*Proceedings of IGY Symposium*, Vol. 2", CSIR, 154.

NUCLEAR RADIATION

1. Goel, P.S., Narasappaya, N., Prabhakara, C., Rama and Zutshi, P.K., (1959), *Tellus*, **11**, 91.
2. Lal, D. Rama, and Zutshi, P.K., (1960), *J. Geophys. Res.* **65**, 664.
3. Rama and Zutshi, P K., (1958), *Tellus*, **10**, 99.
4. Vohra, K.G., Rangarajan C., and Jain, M.C., (1960), *Ind J. Meteor. Geophys.*
5. Vohra, K.G., Rangarajan, C. 1nd Ingle, N.A., (1960), *Ind. J. Meteor. Geophys*
6. Vohra, K.G, and Bhatnagar, V.S., (1962), in "*Proceedings of IGY Symposium*, Vol. 2," CSIR, 244.

SEISMOLOGY

Chakravarty, S.K. and Sarkar, D (1958), *Bull. Scismol. Soc. Ams.*, **48**, 181.
Chakravarty, S.K., (1958), *J. Sci. & Ind. Res.* **17** *Suppl.* 100.
Nanda, J.N., Achynthan K. and Balachandran N.K., (1958) *Nature* **181**, 464.
Nanda, J.N., (1960), *J. Geophys. Res.* **65**, 1815.
Nanda, J.N., (1961), *J. Geophys. Res.*, **66**, 2597.
Saha, B.P., (1963), *Proc. IGY. Symp.* Vol. II, CSIR, 230.
Tandon, A.N., (1963), *Proc. IGY Symp.* Vol. II, CSIR, 207.
Tandon, A.N , (1957), *Ind. J. Met. Geophys.*, **8**, 1.
Tandon, A.N., (1958), *J. Sci. & Ind. Res.*, **17** *Suppl.*, 99.

SPACE RESEARCH

1. Bhatnagar, V.P., (1965), Ph.D. Thesis, Delhi University.
2. Bhatnagar, V.P. and Mitra, A.P , (1966), *J. Atmosph. Terr. Phys.* **23**, 266.
3. Ghosh, S.N. and Bisht, M.S., (1962), *Proc. IGY Symp.* Vol. 2, 1981.
4. Mathur, S.B. and Mitra, A.P., (1960), *J. Sci. & Ind. Res.*, **19A**, 311.
5. Sarada, K.A. and Mitra, A.P., (1962), *Proc. IGY Symp.*, Vol. 2, 206.

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